STIMULUS GENERALIZATION AND DISCRIMINATION ALONG THE DIMENSIONS OF WAVELENGTH AND ANGULAR ORIENTATION

BY

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C. M. B.

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STIMULUS GENERALIZATION AND DISCRIMINATION
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Chapter I

INTRODUCTION

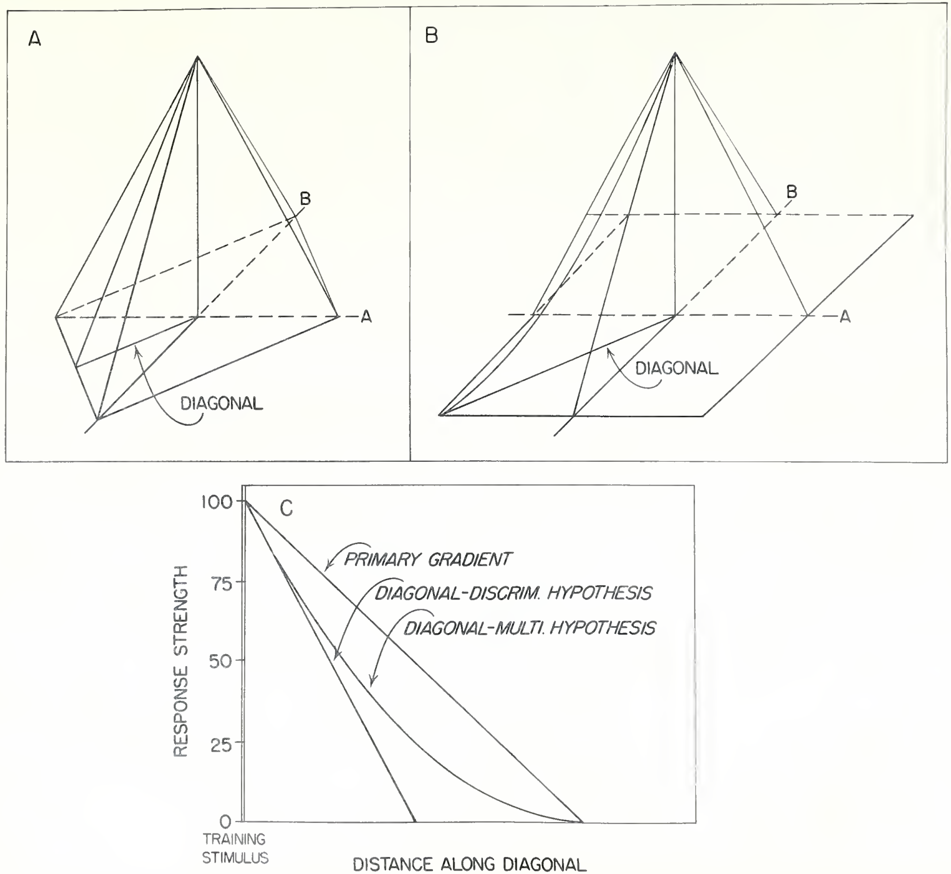
Among the important variables which control the rate of emission of an operant response are the external stimuli in the presence of which the response occurs and/or is reinforced. This fact appears in clear form in studies of stimulus generalization, where systematic changes in response rate occur with variations in some property of the training stimulus along some specified physical dimension.

Previous experiments using pigeons in an operant situation have shown reliable stimulus generalization gradients along the wavelength dimension (Guttman, 1956; Guttman & Kalish, 1956) and have begun to investigate some of the more complex relationships between the generalization gradient and certain other variables (Hanson, 1956; Kalish & Guttman, 1957; Honig, 1958;

Kalish & Guttman, 1959). The present study also uses pigeons in an operant situation and is concerned with the problem of stimulus generalization. The primary purpose of this study was to compare response rates to stimuli which differ from the training stimulus in one and in two dimensions. A related purpose was to attempt a quantitative description of the relationship between response rates under these two sets of conditions in order to be able to predict response rates to stimuli differing from the training stimulus in two dimensions from response rates to stimuli differing in each dimension alone. An experiment using rats (Fink & Patton, 1953) found that the amount of generalization decrement of a tube-drinking response was directly related to the number of stimulus components present in training that were changed. A recent study (White, 1958), using children, found more generalization decrement to stimuli differing from the training stimulus in two dimensions (hue and brightness) than to stimuli differing in either dimension alone. However, no conclusions regarding quantitative relationships between stimulus generalization along one and two dimensions could be reached. The two stimulus dimensions chosen for use in this study were wavelength and angular orientation, both of which have been used in previous studies of stimulus generalization following single stimulus training (Guttman & Kalish, 1956; Butter & Guttman, 1957).

Two alternative relationships between response rates to stimuli varying in one and in two dimensions may be suggested. The models describing such relationships (Fig. 1) consist of generalization gradients along two stimulus dimensions, A and B, set at right angles to each other and

Fig. 1 Predictions of the Discrimination and Multiplicative Hypotheses. A. Generalization surface predicted by the Discrimination Hypothesis. B. Generalization surface predicted by the Multiplicative Hypothesis. C. Comparison between diagonals predicted by the two hypotheses with primary gradient.



A
B
A
DIAGONAL
B
B
A
DIAGONAL
C
PRIMARY GRADIENT
DIAGONAL-DISCRIM. HYPOTHESIS
DIAGONAL-MULTI. HYPOTHESIS
RESPONSE STRENGTH
100
75
50
25
0
TRAINING STIMULUS
DISTANCE ALONG DIAGONAL

intersecting a perpendicular response axis. For simplicity, generalization gradients are drawn as straight lines of equal slope. The alternative relationships between response rates to stimuli varying in one and in two dimensions are specified in terms of the surface connecting the two primary generalization gradients.

One kind of generalization surface is predicted by the Discrimination Hypothesis, which assumes that S responds nonselectively to the sum total of all stimulus energy impinging on its receptors. Likewise, when stimuli are changed, the response strength is a function of the sum of all discriminable stimulus changes, expressed in j.n.d. steps. According to the Discrimination Hypothesis, when a stimulus is changed in two dimensions, the number of j.n.d. steps taken in each dimension alone are summed. The resulting amount of generalization decrement equals the sum of generalization decrements to stimuli changed in each dimension alone.

Thus, if

responses to the training stimulus = x

responses to a stimulus changed along dimension

A = y

responses to a stimulus changed along dimension

B = z

then

x - y = the generalization decrement to a stimulus

changed along dimension A

x - z = the generalization decrement to a stimulus changed

along dimension B

and

$(x - y) + (x - z)$ = the generalization decrement

to a stimulus changed along dimensions A and B

The generalization surface generated by the Discrimination Hypothesis consists of flat planes connecting the two primary gradients (Fig. 1A). This hypothesis has been shown to predict judgments of similarity between multi-dimensional stimuli with only moderate success (Attneave, 1950).

A second hypothesis concerning the relationship between response rates to stimuli varying in one and in two dimensions is the Multiplicative Hypothesis. While the Discrimination Hypothesis assumes that S responds to the sum of all changed stimeli, the Multiplicative Hypothesis assumes that S actively selects and observes each stimulus change independently. A change in the probability of response occurs only if S observes a stimulus change along a particular dimension.

Thus, if

the probability of response to the training

stimulus = 1

the probability of a response to a stimulus

changed along dimension A = r

the probability of response to a stimulus

changed along dimension B = s

then

$1 - r$ = the probability of S observing a stimulus changed along dimension A

$1 - s$ = the probability of S observing a stimulus changed along dimension B

It is assumed that these probabilities of S observing a stimulus change are independent but not mutually exclusive, so that on any short period of time, S observes either a stimulus change along dimension A, a stimulus change along dimension B, a stimulus change along both dimensions, or no change. Thus, on any stimulus presentation period in which the stimulus differs from the training stimulus with respect to both dimensions,

the probability of S observing a change in the training stimulus along dimensions A and B =

$$(1 - r) + (1 - s) - \left[(1 - r)(1 - s)\right] = 1 - rs$$

and

the probability of response to a stimulus changed along dimensions A and B =

$$1 - (1 - rs) = rs$$

Thus, the Multiplicative Hypothesis (Fig. 1B) predicts response probabilities to stimuli changed in two dimensions by multiplying response probabilities to stimuli changed in each dimension alone. This hypothesis was suggested by the results of an exploratory study which utilized a limited number of stimulus values (Butter & Guttman, 1958)

and in a personal communication by Dr. Marvin Levine of the University of Wisconsin. The concept of an "observing response" has been used previously in analyzing discrimination learning (Wyckoff, 1952), while others (Muenzinger & Gentry, 1931; Tolman, 1938) have used the concept of VTE in a similar manner.

Both the Discrimination and the Multiplicative Hypotheses predict lower response rates to stimuli changed in two dimensions than to stimuli changed in each dimension alone. The two hypotheses differ, however, with respect to the size of the predicted difference between these two response rates. This is shown in Fig. 1C, where the diagonals along the two generalization surfaces are compared with a primary generalization gradient. The Discrimination Hypothesis predicts a straight line intersecting the x-axis at a point above which the primary gradient is at 50% response strength. The function predicted by the Multiplicative Hypothesis lies above that predicted by the Discrimination Hypothesis; it is curvilinear and intersects the primary gradient at zero response strength. These two alternative hypotheses concerning the relationships between response rates to stimuli varying in one and in two dimensions are not to be considered as the only possibilities, but as relatively simple alternatives whose psychological significance may be described.

Chapter II

METHOD: EXPERIMENTS 1 AND 2

These experiments are primarily control studies whose purpose was to determine whether response rates to stimuli changed in one dimension are altered by the presence of stimuli varying in another dimension. Experiment 1 concerns wavelength generalization when a narrow band of monochromatic light is transmitted to the key, and Experiment 2 concerns generalization along angular orientation dimension, produced by rotating the band of light, with wavelength constant.

Apparatus: The apparatus was an automatically-controlled Skinner box designed for key-pecking and similar to those used in other wavelength generalization studies (Guttman & Kalish, 1956; Hanson, 1956; Honig, 1958). The special feature of the present apparatus, however, was that only a

narrow band of light was transmitted by the key, and this band could be rotated about its center to provide various degrees of angular orientation. The wavelength of the transmitted light was controlled by monochromatic interference filters placed in the beam illuminating the key.

The light source was a 75 watt (G. E. BLX) projection lamp, focused on the key by means of condensing lenses. In front of the projection lamp a holder was provided for introducing an interference filter in the light path. The 11 interference filters (Bausch & Lomb Co.) used had a band width which varied between 7 and 9 $m\mu$ at half height. The actual peak transmission values of the filters differed from the nominal values as shown in Table 1 on page 11. In subsequent reference to the wavelength stimuli, nominal values will be used. However, in graphs, wavelength values are spaced according to their actual values.

The details of the mechanism for controlling the angular orientation of the band of light on the key are shown in Fig. 2. A circular piece of Insuroc, set within the Lucite frame of the key, was masked in such a manner that a strip running through its center, 1-inch in length and 1/16-inch in width, was exposed to the light beam. The Insuroc circle could be rotated about its center by means of a pair of spur gears. A rod is shown engaging the smaller spur gear; in this position, rotation of the rod produced a rotation of the exposed band about its center. The rod could be moved backwards to disengage the key. The angular orientation of the band of light on the key was set by means of a pointer attached to

Table 1

Nominal and actual peak transmission values of monochromatic interference filters

Nominal value	Actual value
490 Mμ	490.5 Mμ
510	511
520	523
530	538
540	539
550	548
560	561
570	570
580	586
590	589
610	611

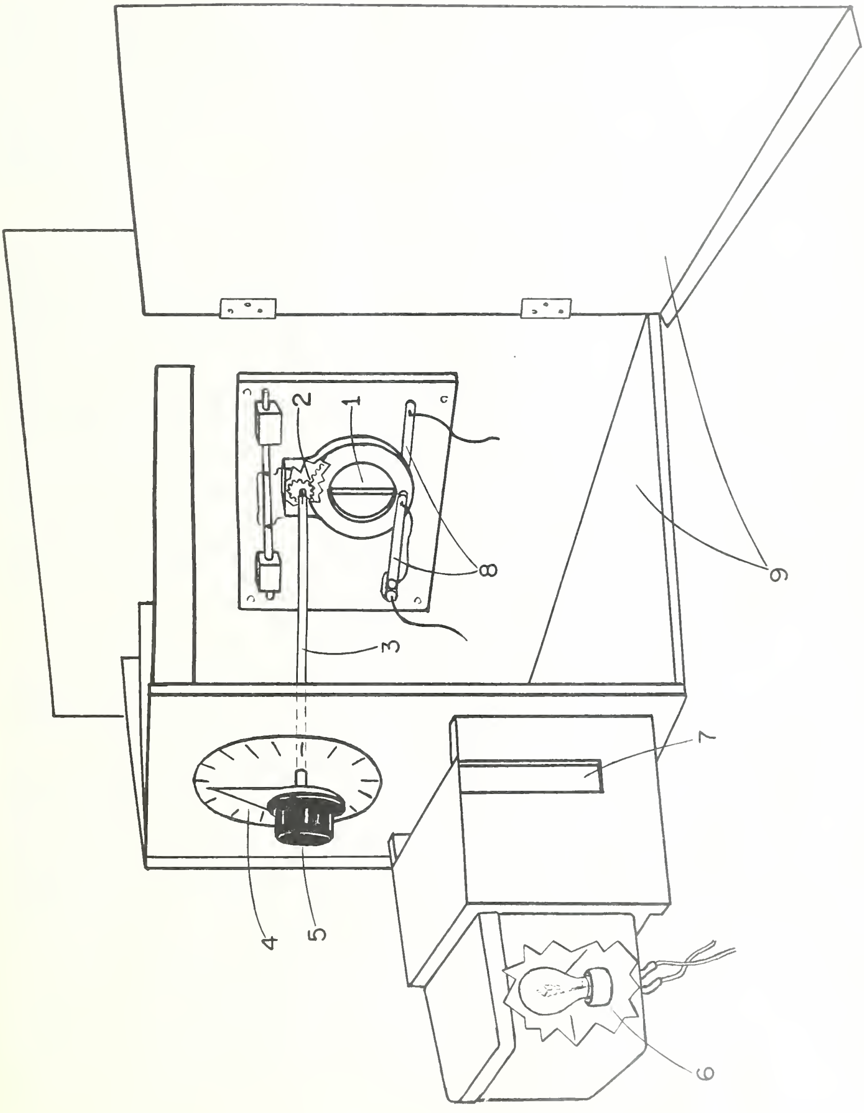
In addition to the filters mentioned, a Wratten K-2 filter (Eastman Kodak Co.) was placed in the light path along with all wavelength values above 550 Mμ. The Wratten filters were used to prevent the transmission of wavelengths below 510 Mμ and any second order spectral wavelengths.*

*It will be noted in Table 1 that the actual peak transmission value of the 530 Mμ interference filter was 538 Mμ (as determined by means of spectrophotometer following the completion of all experiments). Since the actual peak transmission value deviates markedly from the nominal value, it is necessary at this point to consider whether the actual peak transmission value of this filter was 538 Mμ throughout the course of the study or whether it changed at some time during the study. Ss in these experiments were run in the following order: (1) three Ss in Experiment 1, (2) all Ss in Experiment 3, and (3) the remaining six Ss in Experiment 1 and all Ss in Experiment 2. The facts to be presented point to the conclusion that the peak transmission value of this filter changed following the completion of Experiment 3 (reported in Chapter V) and prior to the training and testing of six Ss in Experiment 1.

The generalization gradients obtained from Ss in Experiment 3 following discrimination training show sizeable generalization decrements from 540 to 530 Mμ (Figs. 9-11). On the basis of these generalization decrements, it must be assumed that during the course of testing Ss in Experiment 3, the actual peak transmission values of the 540 and 530 Mμ filters were much

Fig. 2. Diagram of apparatus.

1. Key with exposed band of light running through center.
2. Spur gears.
3. Rod to rotate band of light.
4. Dial.
5. Pointer.
6. Projection lamp in housing.
7. Holder for interference filter.
8. Electric contacts
9. Floor and side wall of housing.


1
2
3
4
5
6
7
8
9

one end of the rod and a dial. Angular orientation settings, calibrated by means of a protractor, were accurate to one degree. The front section (Fig. 2) of the apparatus was enclosed in a light-proof housing, with apertures for the light beam projected on the key and for the rod to rotate the band of light.

The magazine, mounted beneath the floor of the apparatus, was set on a pivot and held in place when not in operation by a cam. The magazine was counterweighted so that when the motor was activated and the cam rotated it was released and rose to the floor of the apparatus. In this position, S could eat grain through a hole in the floor for 3 sec., after which the magazine was returned to its original position by the action of the cam. When the magazine was open, the area of the floor to which it rose was illuminated by a 7 watt lamp.

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further apart than 1 Mμ.

On the other hand, the six Ss in Experiment 1 run subsequent to Ss in Experiment 3 show no significant difference between their responses on the generalization tests to 530 and 540 Mμ. Therefore, it was assumed that during the course of testing these six Ss, the actual peak transmission value of the 530 Mμ filter was 538 Mμ. In analyses of the data from Experiment 1, these six Ss' responses to 538 and 540 Mμ (actual value, 539 Mμ) were averaged and plotted as mean responses to 538.5 Mμ.

It will be assumed in further analyses of the results of Experiment 3 that the 530 Mμ filter had an actual peak transmission value in the region of 530 Mμ. It should be pointed out that in addition to the presumptive evidence upon which this assumption is based, this peak transmission value is subject to an error of ± 4 Mμ, according to the manufacturer.

In addition to the projection lamp and magazine light, a 7 watt lamp was mounted in the ceiling of the apparatus. Masking of relay clicks was provided by white noise from a speaker mounted in the ceiling of the apparatus. The sound source was a Grason-Stadler White Noise Generator, Model 901.

Subjects: The Ss were 18 experimentally naive White Carneau pigeons, obtained from the Palmetto Pigeon Plant, Sumter, South Carolina. They were housed in individual cages where they had tap water available at all times.

Upon arrival at the laboratory, Ss were randomly divided into two groups, Group C and Group T.

Ss were run in three squads: three Ss were in the first squad, seven Ss were in the second squad, and eight Ss were in the third squad.

Procedure: Upon arrival at the laboratory, Ss were fed pigeon grain ad libitum for several days. Ss were then starved to 75 % of their normal body weight (determined on the last day of ad libitum feeding) and maintained at this weight level throughout the experiment.

Magazine training: On the first day of training, S was allowed to eat from the open magazine for three minutes. Any S which did not eat within 30 min. after being introduced into the apparatus was returned to the home cage and trained the next day. On the day following three minutes of feeding in the apparatus, S was trained to approach and eat from the magazine when it was opened. S was introduced into the apparatus, the magazine was opened, and S was allowed to eat for ten sec. On successive

trials, the time the magazine remained opened was gradually shortened until S ate immediately upon presentation of the food. Immediate approach to the opening of the magazine was accomplished in 10-20 trials. During both stages of magazine training the overhead light in the apparatus was on. The key was not illuminated during magazine training.

Key-peck training: On the day following the completion of magazine training, key-pecking was conditioned by the method of "successive approximations," and 50 continuously reinforced key-pecks were permitted. The overhead light in the apparatus was on.

On the second day of key-peck training, Ss were allowed 50 continuous reinforcements, and the overhead light was reduced by putting a piece of paper under the lamp. For all Ss the key was illuminated by monochromatic light of 550 Mμ and the band of light on the key was in vertical position (90°).

V I training: On the day following the completion of key-peck training, Ss began training on a variable interval (V I) reinforcement schedule with a mean interval of one minute. Training sessions consisted of thirty 55-sec. light-on periods, during which the key was illuminated, alternating with 15-sec. light-off periods. V I training was administered over 15 consecutive days. During this time the band of light on the key remained at 550 Mμ and 90°. The overhead light was not on during this and subsequent stages of the experiment.

Generalization testing: On the day following the completion of V I training, Ss were tested for stimulus generalization. Ss which had not

attained the rate of one thousand responses over each of the last three days of V I training were given further training until this criterion was met. Four additional days of training were given to T-5; C-4 and T-7 each received one additional day of training.

Immediately before generalization testing, Ss were presented with the training stimulus (550 Mμ-90°) for six 30-sec. periods, alternating with 15-sec. dark periods. During this "warmup period," key-pecking was reinforced once during the first, third and sixth stimulus periods.

Ss in Group C were tested for generalization along the wavelength dimension. The stimuli consisted of 11 values of wavelength: the training stimulus, 550 Mμ, and five wavelengths above and below this value. The wavelength values were 10 Mμ apart, except for 490 and 610 Mμ. Each stimulus was presented 12 times in random sequence. Each stimulus presentation lasted for 30-sec. and was followed by a 15-sec. dark period.

On the following day, generalization tests were again administered to all Ss. The procedure was the same as on the first day of generalization testing, except that each of the 11 wavelength values was presented eight times. During both days of generalization testing, the angular orientation of the band of light on the key was held constant at 90°.

Ss in Group T were tested for stimulus generalization along the dimension of angular orientation of the band of light. During testing, Ss were presented with 11 values of angular orientation: the training stimulus, 90°, and five values of angular orientation, 15° apart, above and below

this value. On the following day, Ss were given a second generalization test. Except for the stimulus values used in testing, the procedure on both days was identical to that employed with Group C. The wavelength of the band of light was held constant at 550 Mμ throughout testing.

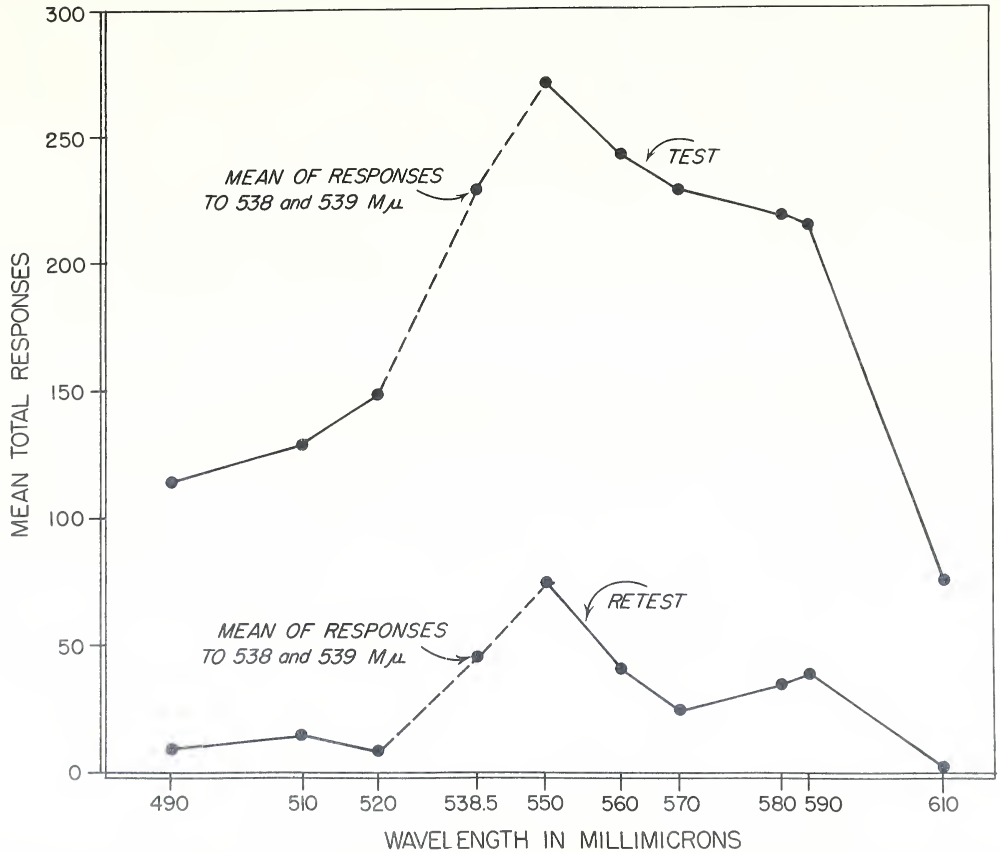
Chapter III

RESULTS: EXPERIMENTS 1 AND 2

Experiment 1, Wavelength generalization: The mean total responses of six Ss in Group C to the 11 wavelength stimuli presented on the first and second day of testing are shown in Fig. 3. Of the nine Ss run in Group C, the six Ss whose responses are averaged in these gradients are those run subsequent to Ss in Group TC and presumptively presented with 538 Mμ in generalization testing. Total responses of the six Ss to 538 and 540 Mμ (actual value, 539 Mμ) were averaged and plotted in Fig. 3 as mean total responses to 538.5 Mμ.

Response rates obtained on the first day of testing are inversely related to distance in wavelength from the training stimulus, 550 Mμ. The averaged generalization gradient is noticeably asymmetrical; response rates to wavelengths above 550 Mμ are greater than response rates to

Fig. 3. Wavelength gradients on test and retest for Experiment 1.



MEAN TOTAL RESPONSES
300
250
200
150
100
50
0
MEAN OF RESPONSES
TO 538 and 539 Mμ
TEST
MEAN OF RESPONSES
TO 538 and 539 Mμ
RETEST
490
510
520
538.5
550
560
570
580
590
610
WAVELENGTH IN MILLIMICRONS

wavelengths below this value, except at 610 Mμ, where response rates are lower than to 490 Mμ.

The averaged generalization gradient obtained on the second day of testing is similar in form to the one obtained on the first day. Response rates on the second day are inversely related to distance in wavelength from 550 Mμ, and response rates to wavelengths above 550 Mμ are greater than response rates to wavelengths below this value, except at 610 Mμ, where response rates are slightly less than those to 490 Mμ.

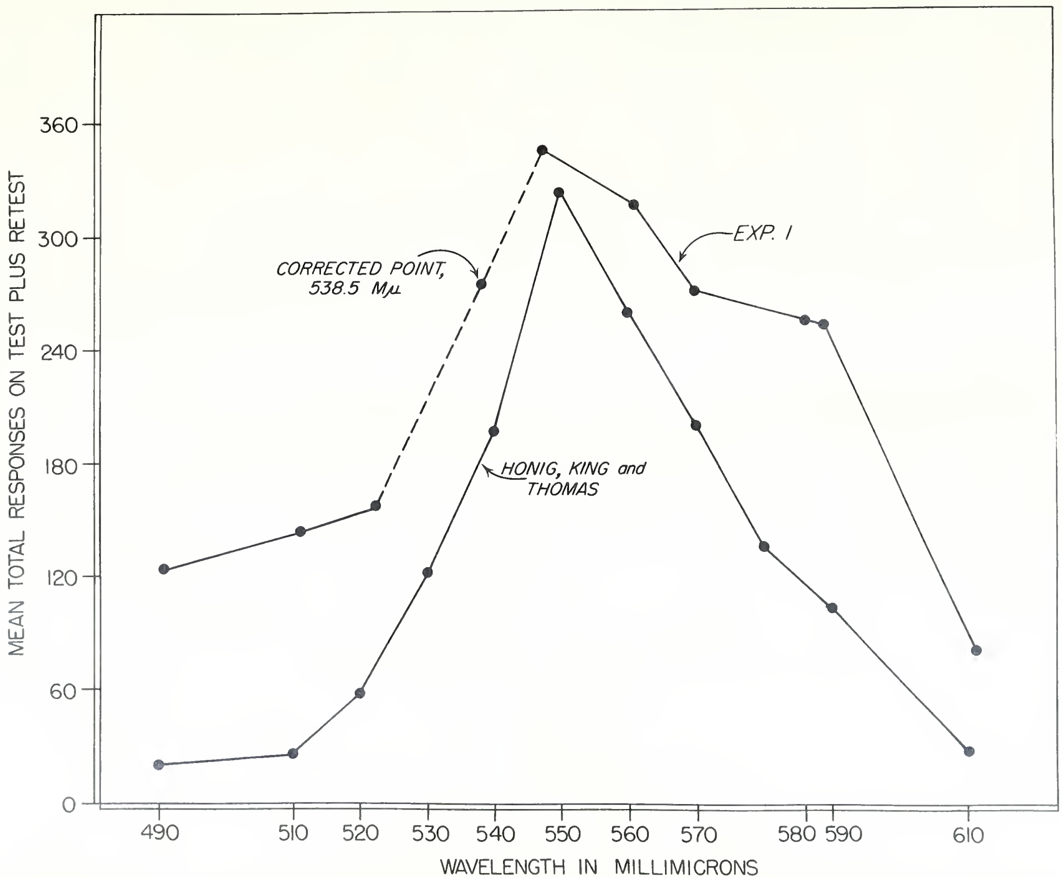
Examination of the response rates of individual Ss on both days of testing discloses, on the whole, the same asymmetries found in averaged generalized response rates.* Response rates of eight of the nine Ss to 560 and 590 Mμ are greater than their response rates to 540 and 510 Mμ, respectively. Response rates of all nine Ss to 580 Mμ are greater than their response rates to 520 Mμ. These findings are all the more striking when it is considered that the actual values of the 560, 580 and 590 Mμ filters are further from the training stimulus than are the actual values of the 540, 520 and 510 Mμ filters, respectively (see Table 1, page 11). Response rates of six of the nine Ss to 490 Mμ are greater than their response rates to 610 Mμ. This finding is in accordance with the fact that the actual value of the 610 Mμ filter is further from the training stimulus

*The responses of all nine Ss in Group C were examined. Responses to 530 Mμ were not considered because of the change in the peak transmission value of this filter.

than is the actual value of the 490 Mμ filter (see Table 1, page 11). Thus, the pattern of the individual scores lends support to the conclusion that the asymmetries described above represent true differences in the pattern of responding.

Response rates of the same six Ss to the 11 wavelength stimuli presented on the first and second day of testing are summed and averaged in the generalization gradient shown in Fig. 4. In the same figure, a generalization gradient obtained under comparable conditions but with the full key illuminated with monochromatic light during training to 550 Mμ and testing (Honig, Thomas & King, in press) is shown. This generalization gradient consists of mean total responses of 11 Ss to 24 exposures to each wavelength stimulus presented on two days of testing. Stimulus values plotted along the abcissa are the actual values employed in the Honig, Thomas & King study, while the actual values employed in the present study are used to plot Group C's gradient. The small differences between stimulus values employed in the present study and that of Honig, Thomas & King preclude statistical comparisons between the response rates obtained in the two experiments. However, from inspection, it is clear that the gradient obtained in the present study is broader throughout its range than the one obtained with the full key illuminated, especially in the region of wavelength values distant from 550 Mμ. At 490 Mμ, mean response rates in the present study comprise approximately 30% of response rates to 550 Mμ, whereas approximately 6% of mean response rates to 550 Mμ are shown at 490 Mμ by Ss in the Honig, Thomas & King study. Although the slope

Fig. 4. Wavelength gradient for Experiment 1 and for experiment of Honig, Thomas & King.



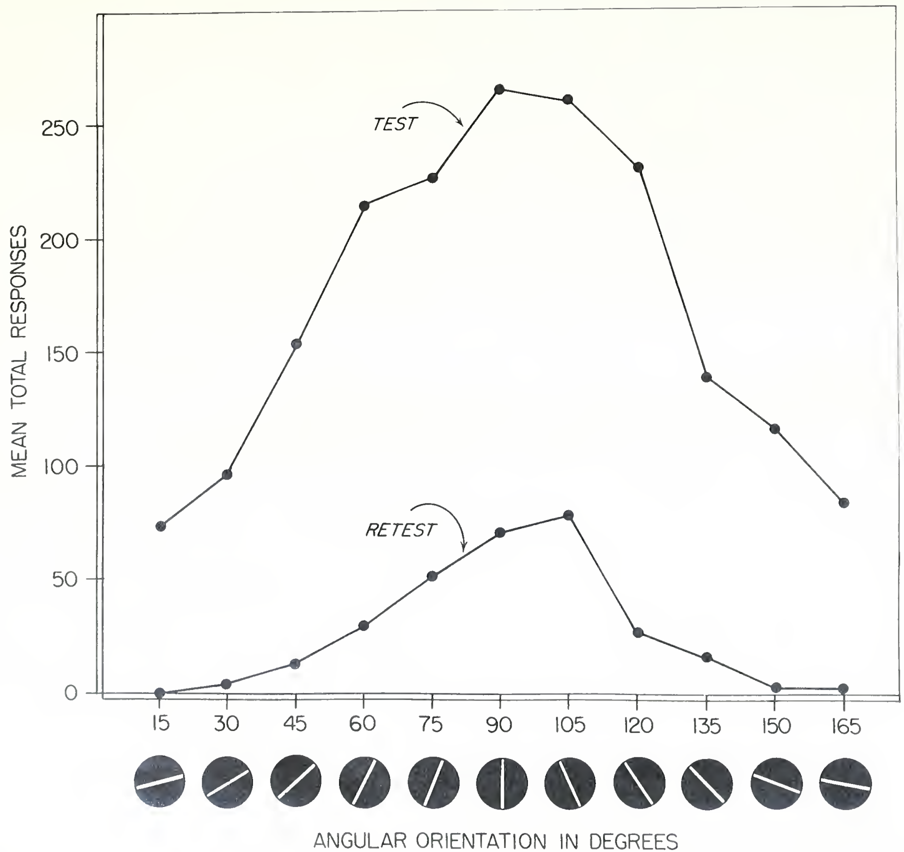
360
300
240
180
120
60
0
MEAN TOTAL RESPONSES ON TEST PLUS RETEST
CORRECTED POINT, 538.5 Mμ
EXP. I
HONIG, KING and THOMAS
490
510
520
530
540
550
560
570
580
590
610
WAVELENGTH IN MILLIMICRONS

between 590 and 610 Mμ in the present study is steeper than that found in the study using the fully illuminated key, mean response rates of Ss in Group C to 610 Mμ are approximately 19% of response rates to 550 Mμ, whereas approximately 9% of response rates to 550 Mμ are given to 610 Mμ by Ss in the latter study.

Experiment 2, Angular orientation generalization: The mean total responses of Ss in Group T to the 11 values of angular orientation presented on the first and second day of testing are shown in Fig. 5. (Representations of the actual stimuli are shown below each stimulus value on the ordinate.) Mean response rates obtained on the first day of testing are inversely related to distance in degrees from the training stimulus, 90°, and the generalization gradient plotted in Fig. 5 forms slightly bow-shaped functions, especially the one above 90°. The same generalization gradient contains several asymmetries; the most obvious one consists of the greater number of mean response rates to 105° than to 75°. Less striking but still noticeable are the higher number of mean response rates to 120°, 150°, and 165° than to equidistant stimulus values below 90°. In addition, mean response rates to 45° are higher than mean response rates to 135°.

Mean total responses obtained on the second day of testing are also inversely related to distance in degrees from 90°, except for the inversion at 105°, where the peak of responding is located. Mean response rates on the second day of testing to other values of angular orientation above 90° are not strikingly different from mean response rates to

Fig. 5. Angular orientation gradients on test and retest for Experiment 2.


TEST
RETEST
MEAN TOTAL RESPONSES
0
50
100
150
200
250
15
30
45
60
75
90
105
120
135
150
165
ANGULAR ORIENTATION IN DEGREES

equidistant stimulus values below 90°.

Response rates of individual Ss on both days of testing were examined in order to determine whether the asymmetries described above represent true differences in responding. Response rates of seven of the nine Ss to 105° and 120° are higher than their response rates to 75° and 60°, respectively. However, comparison of individual Ss' response rates to other stimuli equidistant from 90° disclosed consistent differences in response rates in, at best, only five of the nine Ss' scores. Thus, the pattern of the individual scores supports the conclusion that mean response rates to 105° and 120° are significantly higher than mean response rates to 75° and 60° respectively, but that the asymmetries involving other angular orientation stimuli do not represent true differences in responding.

Chapter IV

METHOD: EXPERIMENT 3

Apparatus: The apparatus was the same as that used in Experiments 1 and 2.

Subjects: Ss were 27 experimentally naive White Carneau pigeons, obtained from the Palmetto Pigeon Plant, Sumter, South Carolina. Prior to the experiment they were treated in the same manner as Ss in Experiments 1 and 2. Two Ss, TC-121 and TC-128, were discarded because of failure to train. Ss were run in five squads; five Ss were run in four squads and seven in the fifth squad.

Procedure: Weight reduction and magazine training were accomplished in the same manner as in Experiments 1 and 2. Likewise, key-peck training and V I training were administered as in previous experiments; the training stimulus was maintained at 550 Mμ-90° throughout

key-peck and V I training. One S, TC-141, was given one further day of training in order to meet the V I training criterion of at least 1000 responses on each of three consecutive days.

Generalization testing: On the day following the completion of V I training, all Ss were administered generalization tests. Immediately prior to generalization testing a "warmup period" was administered to all Ss in the same manner as in Experiments 1 and 2. The 25 stimuli which were presented in generalization testing were composed of all combinations of five values of wavelength, 530, 540, 550, 560, and 570 mμ, with five values of angular orientation, 30°, 60°, 90°, 120° and 150°. Each stimulus combination was presented once in each of six series according to the following design. The first series, in which stimuli were presented in a randomized order, was divided into five blocks of four stimuli and one block of five stimuli. The six series of blocks formed a Latin Square design in which each block occupied each of the six positions over all series.

Table 2

Position of stimulus blocks on first day of generalization testing (Exp. 3)

Position in series		1	2	3	4	5	6
	1	I	II	IV	VI	III	V
	2	II	III	V	I	IV	VI
	3	III	IV	VI	II	V	I
	4	IV	V	I	III	VI	II
	5	V	VI	II	IV	I	III
	6	VI	I	III	VI	II	IV

On the following day, all Ss received a second generalization test in which the last three series of stimuli used on the first day of generalization testing were presented in a backward order.

Discrimination training: The purpose of this part of Experiment 3 was to describe discrimination learning involving stimuli differing in one and in two dimensions. Following the completion of generalization testing, the 27 Ss were divided into three groups of nine each: Group TC-C, TC-T and TC-TC. Assignment of Ss to groups was made so as to equalize average response rates over the last three days of V I training for each of the three groups.* Group TC-C received discrimination training along the wavelength dimension (550 Mμ-positive; 560 Mμ-negative) with angular orientation held constant at 90°. Group TC-T received discrimination training along the angular orientation dimension (90° - positive; 120° - negative) with wavelength held constant at 550 Mμ. Group TC-TC received discrimination training along both the dimensions of wavelength and angular orientation (550 Mμ-90°, positive; 560 Mμ-120°, negative).

Immediately prior to the first discrimination training session, all Ss were permitted ten continuously reinforced key-pecks in the presence of the pre-generalization training stimulus. Ss in all three groups received daily discrimination training sessions consisting of 15 presentations of the positive and negative stimuli in a randomized sequence. Key-pecking

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*The hypothesis that average response rates were the same for all three groups could not be rejected by the results of Mann-Whitney U tests.

in the presence of the positive stimulus was reinforced on the same V I schedule used in prior V I training, while pecking in the presence of the negative stimulus was never reinforced. Daily discrimination training sessions were continued until the criterion of complete suppression of responding to ten consecutive presentations of the negative stimulus and maintainance of at least ten responses to each of ten consecutive presentations of the positive stimulus was met.

This criterion was not met by two Ss, one in Group TC-C (TC-126) and one in Group TC-T (TC-123). Discrimination training for both Ss was ended after 30 days.

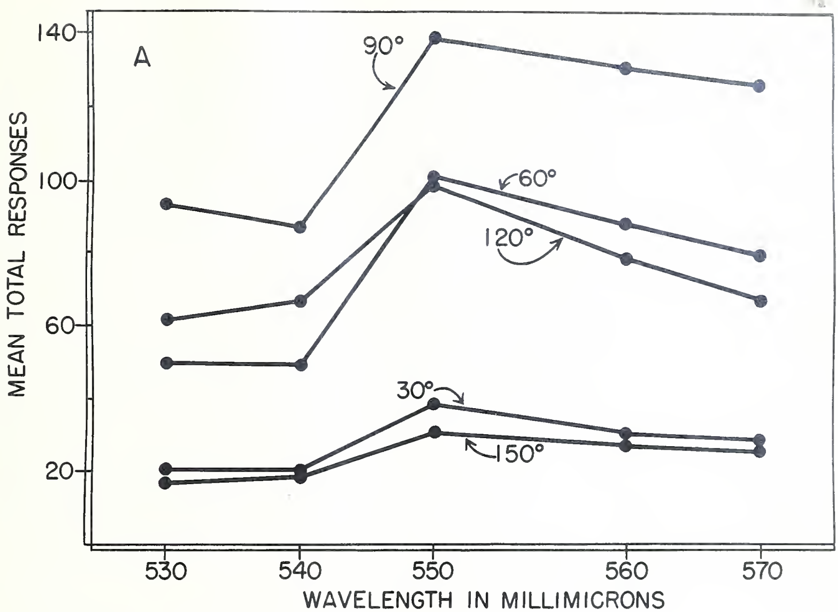
Post-discrimination generalization testing: A further problem to which this study is directed is a determination of changes in the form of stimulus generalization along one and two dimensions following discrimination training. On the day following the completion of discrimination training, all Ss were administered generalization tests in which the same 25 stimuli administered in pre-discrimination generalization tests were presented in the same Latin Square design. No "warmup period" was presented prior to generalization testing. On the following day, a second generalization test was administered in the same manner as in pre-discrimination generalization testing.

Chapter V

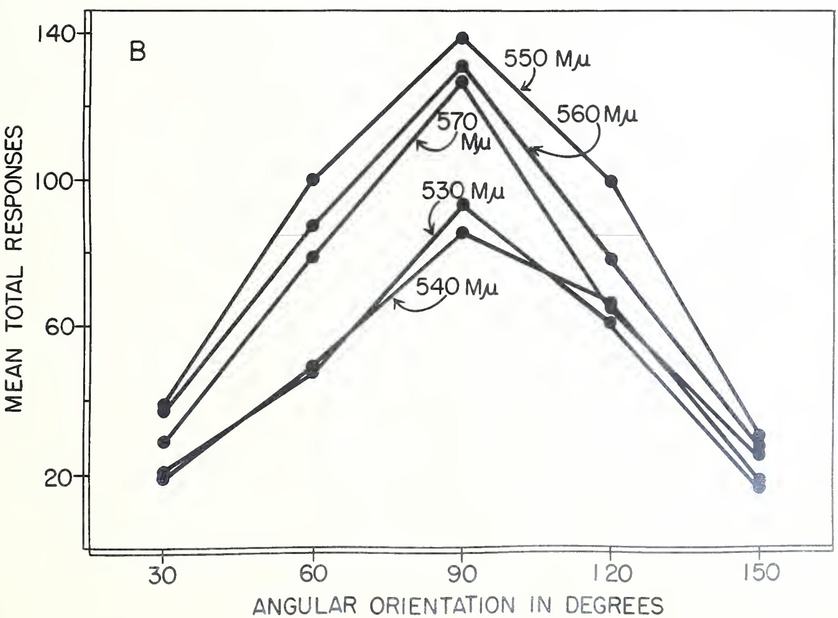
RESULTS: EXPERIMENT 3

Stimulus generalization along the wavelength and angular orientation dimensions following training at 550 Mµ-90°: (Tables 5 and 6, Appendix) For ease of inspection, the results of this part of Experiment 3 are presented as generalization gradients along each stimulus dimension for different values of the second dimension. Mean total responses of Ss in Group TC to the 25 stimuli presented on the first day of generalization testing are plotted as a function of wavelength with angular orientation as a parameter in Fig. 6A. The averaged wavelength generalization gradients are all asymmetrical in the same direction as wavelength gradients obtained in Experiment 1 (Fig. 3). Mean response rates to 560 and 570 Mµ are higher than mean response rates to 540 and 530 Mµ.

Fig. 6. Gradients for Experiment 3 (Group TC) on first day of testing. A. Wavelength gradients at different angular orientation values. B. Angular orientation gradients at different wavelength values.



A
MEAN TOTAL RESPONSES
140
100
60
20
90°
60°
120°
30°
150°
530
540
550
560
570
WAVELENGTH IN MILLIMICRONS



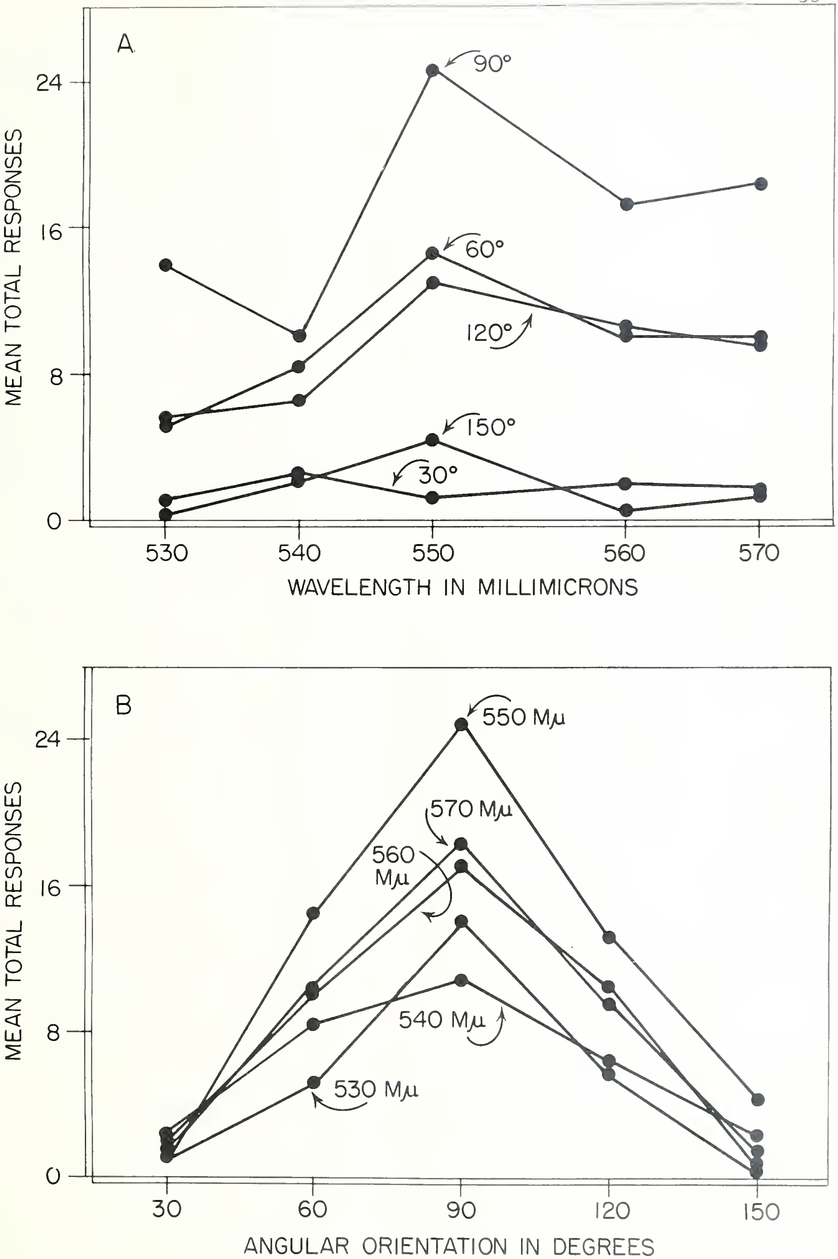
B
MEAN TOTAL RESPONSES
140
100
60
20
550 Mμ
560 Mμ
570 Mμ
530 Mμ
540 Mμ
30
60
90
120
150
ANGULAR ORIENTATION IN DEGREES

All generalization gradients show decrements from 550 to 540 Mμ and little or no decrement from 540 to 530 Mμ. Generalization decrements to wavelengths above 550 Mμ are all quite small. Furthermore, gradients at 30° and 150° are flatter than those at levels of angular orientation closer to 90°. Averaged wavelength generalization gradients obtained on the second day of testing (Fig. 7A) are similar to those obtained on the first day. Generalization decrement to wavelengths above 550 Mμ is smaller than to wavelengths below 550 Mμ, except at 30° and 150°, where generalization gradients are essentially flat. It is also noted that wavelength gradients at 60° and 120° are in general flatter than the gradient at 90°.

Mean total responses of the same Ss on the first day of testing are plotted as a function of angular orientation with wavelength as a parameter in Fig. 6B. It is seen, first of all, that over the range of angular orientation values at which generalization was tested, there is proportionally more generalization decrement than is found over the range of wavelength values shown in Fig. 6A. Mean total responses obtained on the first day of testing are inversely related to distance in degrees from the angular orientation training stimulus, 90°. The angular orientation gradients show no consistent asymmetries, but differences in form are noticeable; gradients at 530 and 540 Mμ are flatter from 30° to 60° and from 120° to 150° than are gradients at other wavelength values.

Averaged angular orientation gradients obtained on the second day of

Fig. 7. Gradients for Experiment 3 (Group TC) on second day of testing. A. Wavelength gradients at different angular orientation values. B. Angular orientation gradients at different wavelength values.


A
90°
60°
120°
150°
30°
MEAN TOTAL RESPONSES
0
8
16
24
530
540
550
560
570
WAVELENGTH IN MILLIMICRONS
B
550 Mμ
570 Mμ
560 Mμ
540 Mμ
530 Mμ
MEAN TOTAL RESPONSES
0
8
16
24
30
60
90
120
150
ANGULAR ORIENTATION IN DEGREES

testing (Fig. 7B) are not markedly different from those obtained on the first day of testing. Mean total responses obtained on the second day of testing are inversely related to distance in degrees from 90°, and no consistent asymmetries appear in the set of gradients. Again, angular orientation gradients at 540 and 530 Mμ are flatter from 30° to 60° and from 120° to 150° than gradients at other wavelength values.

The results of this part of Experiment 3 may be analyzed in order to determine whether there is any consistent difference between mean response rates to the 16 stimuli varying in two dimensions and mean response rates to each of the two stimuli varying to the same extent in only one dimension. For example, response rates to 530 Mμ-30° may be compared with response rates to 530 Mμ-90° and with response rates to 550 Mμ-30°. Total responses of individual Ss on both days of testing were transformed into logs in order to normalize response distributions, and differences between mean log response rates to stimuli varying in one and in two dimensions with respect to the training stimulus were analyzed by means of the _t_ test for correlated scores (Walker & Lev, 1953) in Table 7 (Appendix). In 29 cases, mean log response rates to stimuli varying in two dimensions were significantly lower ($p < .05$) than mean log response rates to stimuli varying only in one dimension. In the remaining three cases, this difference approached significance ($.1 > p > .05$). Thus, mean log response rates to stimuli differing from the training stimulus in two dimensions are consistently lower than mean log response rates to stimuli differing from the training stimulus in each dimension alone.

The generalization data may be further analyzed from the viewpoint of describing the quantitative relationship between response rates to stimuli differing from the training stimulus in one and in two dimensions. Mean response rates to the 16 stimuli differing in two dimensions from the training stimulus are compared with mean response rates to these same stimuli predicted by the Discrimination and Multiplicative Hypotheses in Table 8 (Appendix).* The standard error of the estimate was used to describe the accuracy of descriptions.** The overall standard error for the Discrimination Hypothesis is 17.3, while the overall standard error for the Multiplicative Hypothesis is 9.4. In regard to the direction of prediction errors, 13 of the 16 predictions of the Discrimination Hypothesis are lower than mean obtained response rates, while 11 of the 16 predictions of the Multiplicative Hypothesis are greater than mean obtained response rates.

The mean response rates to be predicted may be divided into two groups: eight low response rates (response rates to stimuli including 30° and 150°) and eight high response rates (response rates to stimuli including 60° and 120°). For the eight low response rates, the standard error for the Discrimination Hypothesis is 15.3, while the standard error for the Multiplicative Hypothesis is 2.7. The Discrimination Hypothesis

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*Both sets of predictions were computed according to the formulas described in Chapt. I on the basis of mean responses of the 27 Ss on both days of generalization testing.

**$\sigma_{yx} = \sqrt{\frac{\Sigma d^2}{N-1}}$, where d = deviation of predicted from obtained mean response rates.

underpredicts all eight mean response rates, and the Multiplicative Hypothesis underpredicts four of these eight mean response rates.

For the eight high response rates, the standard error for the Discrimination Hypothesis is 10.7, while that for the Multiplicative Hypothesis is 9.0. Thus, the major source of difference between prediction accuracy of the Discrimination and Multiplicative Hypotheses is attributed to predictions of low response rates.

The effect on stimulus generalization along one dimension of variations in a second dimension: In this section, the results of Experiments 1 and 3 are compared in order to determine whether stimulus generalization along the wavelength dimension is changed by the presence of variations in angular orientation. Mean total responses of Ss in Group TC to 540, 560 and 570 Mμ (angular orientation = 90°) and mean total responses of Ss in Group C to the same stimuli are shown in Table 9 (Appendix)*. Responses of Ss in Group TC were raised by a constant amount in order to match their mean peak of responding at 560 Mμ-90° to that of Ss in Group C. None of the differences between mean response rates of the two groups to any of the three wavelength stimuli are significantly different by the t test (in all cases, $p > .75$).

By comparing the results of Experiments 2 and 3, it may be determined whether stimulus generalization along the angular orientation

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*Because it is assumed that the peak transmission value of the 530 Mμ interference filter changed before six Ss in Group TC were run, no comparison of responses of Ss in the two groups to the wavelength produced by this filter can be made.

dimension is changed when stimuli are also varying along the wavelength dimension. Mean total responses of Ss in Group TC to 30°, 60° 120°, and 150° (Mμ = 550) and mean total responses of Ss in Group T to the same stimuli are shown in Table 10 (Appendix). Responses of Ss in Group TC were raised by a constant amount to match their mean peak of responding at 550 Mμ-90° to that of Ss in Group T. Differences between mean response rates of the two groups to 60° and 120° are not significantly different as determined by t tests (in both cases, $p > .75$). However, mean response rates of Ss in Group TC to 30° and 150° are significantly greater than mean response rates of Ss in Group T to these same stimuli (in both cases, $p < .05$). Thus, while stimulus generalization to the three wavelength stimuli is not changed by the presence of variations in angular orientation, generalized response rates to two angular orientation stimuli are greater when wavelength stimuli are concomitantly varied.

Discrimination training: The number of days taken by the three discrimination groups to attain the discrimination learning criterion following generalization testing are shown in Table 11 (Appendix). The mean number of days for the Wavelength Discrimination Group (Group TC-C) was 14.7, for the Angular Orientation Group (Group TC-T), 17.3, and for the Wavelength-Angular Orientation Group (Group TC-TC), 9.0. The distributions of days to discrimination criterion for each of the three groups were compared by the Mann-Whitney U test (Seigel, 1956) in Table 11. Days to discrimination criterion for Group TC-TC were significantly less than those for Group TC-T ($.02 > p > .005$) and less than those for

Group TC-C, the difference in the latter case approaching significance ($.1 > p > .05$). Days to discrimination criterion for Groups TC-C and TC-T were not significantly different ($p > .1$).

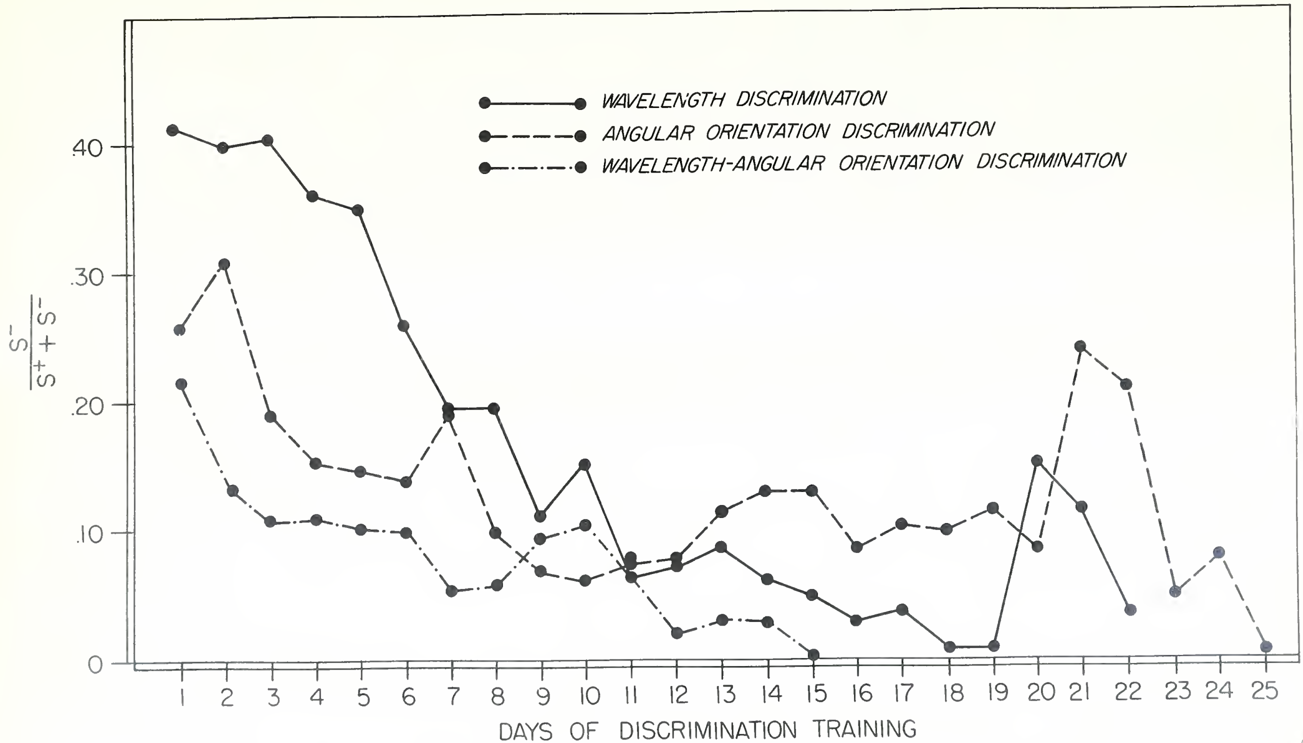
The course of discrimination learning for the three groups is shown in Fig. 8. The three curves are composed of mean proportions of daily total responses of Ss in each group to the S^-. Two Ss, one in Group TC-C (TC-C-126), and one in Group TC-T (TC-T-123) failed to meet the discrimination learning criterion after 30 days of training and were left out of this analysis.

Differences between the three groups mean proportions of responses to the S^- appear on the first day of discrimination training. The mean proportion of responses to the wavelength ("C") S^- (560 $M\mu$-90^o) is .414, to the angular orientation ("T") S^- (550 $M\mu$-120^o), .257, and to the wavelength angular orientation ("TC") S^- (560 $M\mu$-120^o), .215.

Whereas the proportion of responses to the TC S^- starts to decline immediately, the proportion of responses to the C S^- remains at approximately the same level for the first three days of discrimination training before declining, and the proportion of responses to the TC S^- rises on the second day before declining.

On the first 12 days of discrimination training, the proportion of responses to the C S^- falls more rapidly than do proportions of responses to the T or to the TC S^-'s. While the curve for Group TC falls to zero on the 15th day of training, the curve for Group T levels off around .1 from the 13th to the 20th day, and the curve for Group C continues to fall

Fig. 8. Proportions of total responses to S^{-} in discrimination training for Groups TC-C, TC-T and TC-TC.

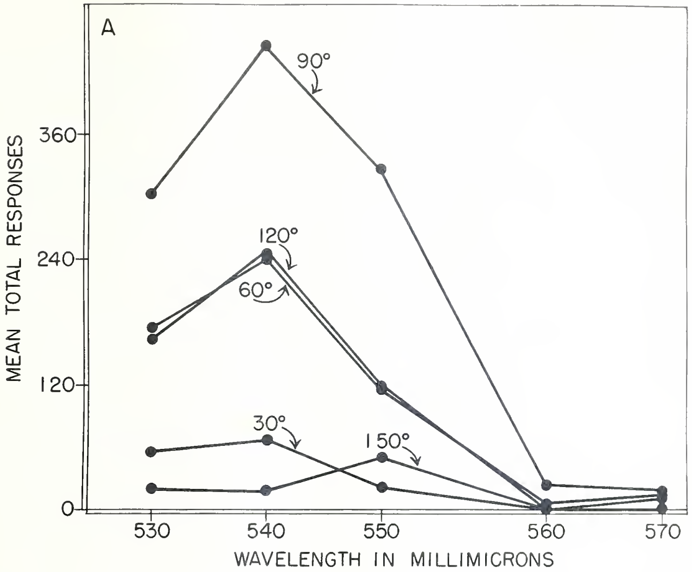

WAVELENGTH DISCRIMINATION
ANGULAR ORIENTATION DISCRIMINATION
WAVELENGTH-ANGULAR ORIENTATION DISCRIMINATION
$\frac{S^-}{S^+ + S^-}$
.40
.30
.20
.10
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25
DAYS OF DISCRIMINATION TRAINING

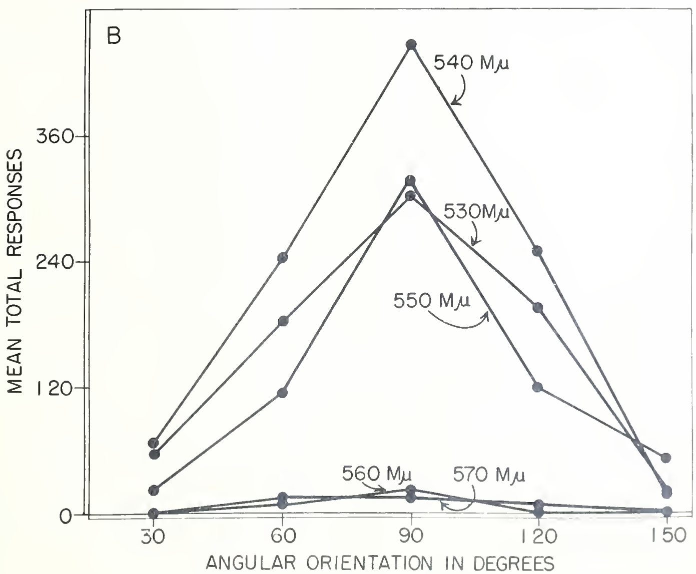
until the 20th day, when it rises sharply to .237 and then drops again. Similarly, on the 21st day, the curve for Group T rises sharply to .145 and then drops again. The curve for Group C contains responses of only one S following the 19th day of discrimination training, and that of Group T also contains the responses of only one S following the 20th day of training. Thus, the rises in proportions of responses to S^- described above can be attributed to chance fluctuations.

Generalization following wavelength discrimination: (Tables 12 and 13, Appendix) Mean total responses of nine Ss, summed over both generalization tests following wavelength discrimination, are shown in Fig. 9. Wavelength generalization gradients at different values of angular orientation (Fig. 9A) all show suppression of responding to 560 Mμ, the S^- in discrimination training, and 570 Mμ. In comparison with wavelength generalization gradients obtained before discrimination training, (Fig. 6 and 7), these gradients are much steeper between 560 and 570 Mμ. Peaks of responding are at 540 Mμ, except for the gradient at 150°, which peaks at 550 Mμ. In addition, gradients which have peaks at 540 Mμ are asymmetrical; responses to 530 Mμ are greater than responses to 550 Mμ. It is also noted that gradients at 30° and 150° are flatter than those at levels of angular orientation closer to 90°.

In Fig. 9B, mean total responses on both days of generalization testing are plotted as a function of angular orientation, with wavelength as a parameter. Response rates to 560 and 570 Mμ are markedly suppressed, and gradients are found only at 550, 540 and 530 Mμ. The

Fig. 9. Gradients obtained following wavelength discrimination (Group TC-C). A. Wavelength gradients at different angular orientation values. B. Angular orientation gradients at different wavelength values.


A
90°
120°
60°
30°
150°
MEAN TOTAL RESPONSES
360
240
120
0
530
540
550
560
570
WAVELENGTH IN MILLIMICRONS

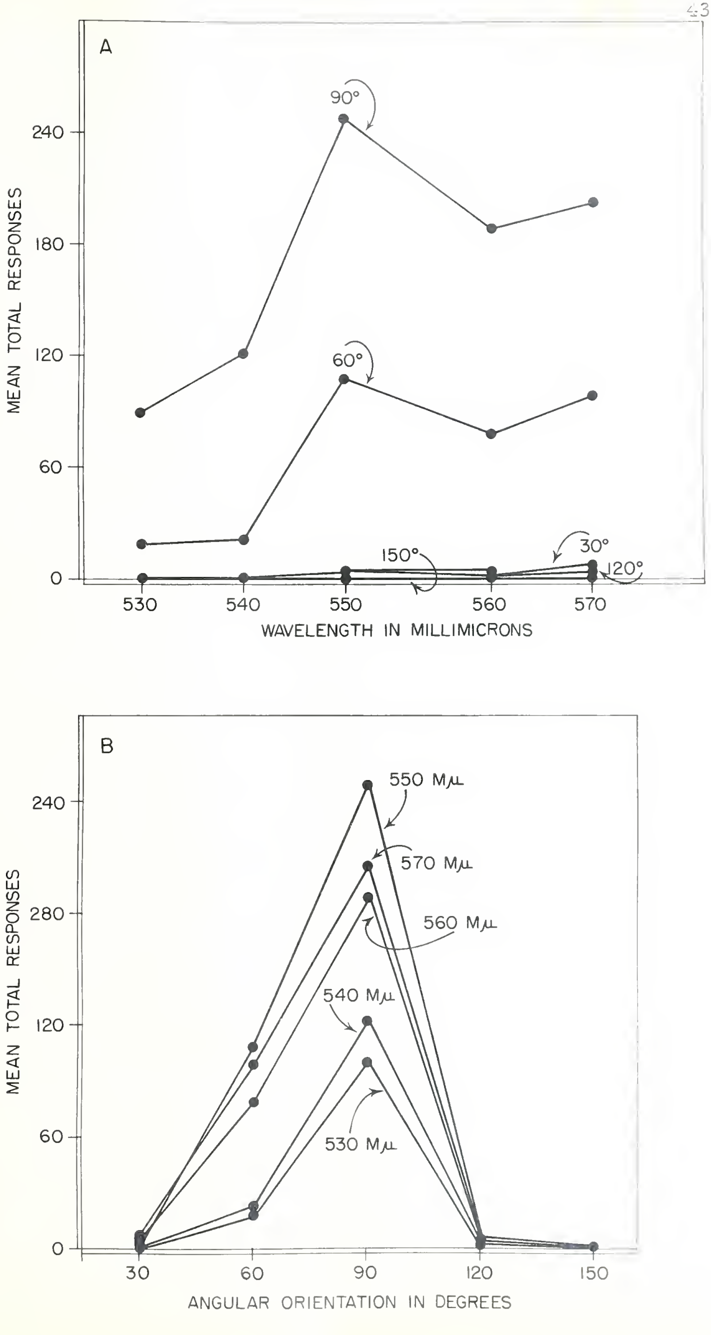

B
540 Mμ
530Mμ
550 Mμ
560 Mμ
570 Mμ
MEAN TOTAL RESPONSES
360
240
120
0
30
60
90
120
150
ANGULAR ORIENTATION IN DEGREES

averaged angular orientation gradients peak at 90°, and response rates are inversely related to distance in degrees from 90°.

Generalization following angular orientation discrimination: (Tables 15 and 16, Appendix) Mean total responses of nine Ss summed over both days of generalization testing following angular orientation discrimination training are shown in Fig. 10. Averaged angular orientation generalization gradients at different wavelength values (Fig. 10B) all show suppression of responding to 120°, the S^- in discrimination training, and to 30° and 150°. In comparison with angular orientation gradients obtained before discrimination training (Fig. 6B and 7B), slopes between 90° and 120° are much steeper, and there is greater responding to 60° than to 120°. In addition, the gradient at 530 Mμ is flatter between 90° and 60° than gradients at other wavelength values.

Mean total responses on both days of testing are plotted as a function of wavelength for different values of angular orientation in Fig. 10A. Response rates to 30°, 120° and 150° are markedly suppressed so that generalization gradients are found only at 60° and 90°. Both gradients are asymmetrical in the same direction as wavelength gradients obtained prior to discrimination training (Fig. 6A and 7A); response rates to 560 and 570 Mμ are greater than response rates to 540 and 530 Mμ, respectively. Also, response rates to wavelength stimuli below 550 Mμ are inversely related to distance from 550 Mμ, while response rates to 570 Mμ are slightly higher than response rates to 560 Mμ.

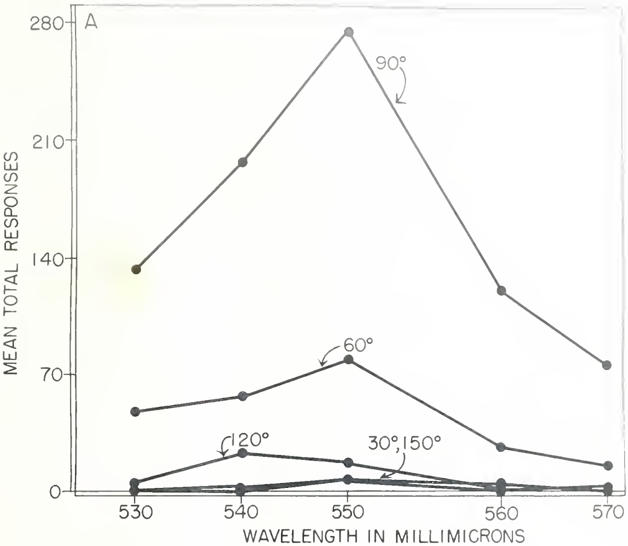
Fig. 10 Gradients obtained following angular orientation discrimination (Group TC-T). A. Wavelength gradients at different angular orientation values. B. Angular orientation gradients at different wavelength values.

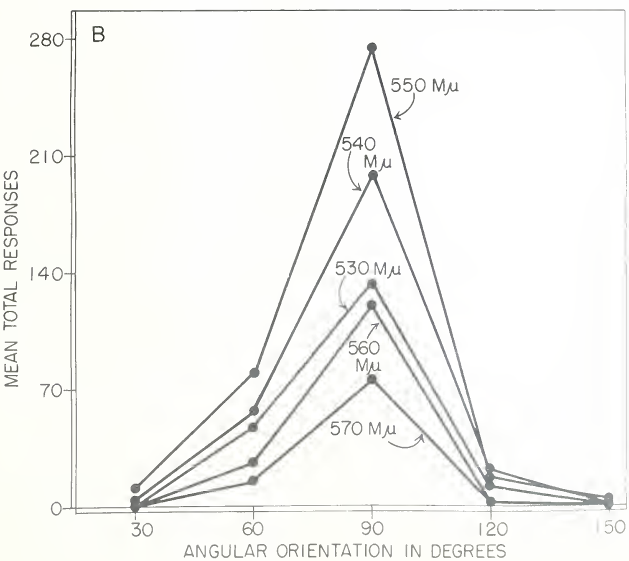

A
90°
60°
150°
30°
120°
240
180
120
60
0
MEAN TOTAL RESPONSES
530
540
550
560
570
WAVELENGTH IN MILLIMICRONS
B
550 Mμ
570 Mμ
560 Mμ
540 Mμ
530 Mμ
240
280
120
60
0
MEAN TOTAL RESPONSES
30
60
90
120
150
ANGULAR ORIENTATION IN DEGREES

<u>Generalization following wavelength-angular orientation discrimination:</u> (Tables 18 and 19, Appendix) Mean total responses of nine Ss summed over both days of generalization testing following wavelength-angular orientation discrimination training are shown in Fig. 11. Averaged angular orientation generalization gradients (Fig. 11B) are quite similar to those obtained following angular orientation discrimination (Fig. 10B); there is almost complete suppression of responding to 120°, 150°, and 30°. All gradients show peaks of responding at 90° and higher response rates to 60° than to 120°. In addition, gradients at 530, 560 and 570 Mμ are noticeably flatter than gradients at 540 and 550 Mμ.

Mean total responses on both days of generalization testing are plotted as a function of wavelength with angular orientation as a parameter in Fig. 11A. Since response rates to 30° and 150° are markedly suppressed, the only wavelength gradients are at 90°, 60° and 120°. These gradients are noticeably different from those obtained following wavelength discrimination training (Fig. 9A); gradients at 60° and 90° peak at 550 Mμ, and the gradient at 120° peaks at 540 Mμ. However, the differences in response rates to 550 and 540 Mμ at 60° and 120° are small. In addition, the gradients at 60° and 90° show much less response suppression to 560 Mμ (the wavelength S^- in discrimination training) than do post-wavelength discrimination gradients. Response suppression to 560 Mμ is also noticeably less than response suppression to 120° (the angular orientation S^- in discrimination training) (Fig. 11B).

Fig. 11. Gradients obtained following wavelength-angular orientation discrimination (Group TC-TC). A. Wavelength gradients at different angular orientation values. B. Angular orientation gradients at different wavelength values.


A
MEAN TOTAL RESPONSES
280
210
140
70
0
90°
60°
120°
30°,150°
530
540
550
560
570
WAVELENGTH IN MILLIMICRONS


B
MEAN TOTAL RESPONSES
280
210
140
70
0
550 Mμ
540 Mμ
530 Mμ
560 Mμ
570 Mμ
30
60
90
120
150
ANGULAR ORIENTATION IN DEGREES

Mean response rates to 120° at all levels of wavelength are 9.8, while mean response rates to 560 Mμ at all levels of angular orientation are 30.8.

<u>Predictions of post-discrimination generalization in two dimensions:</u> The standard error of the estimate was used to measure accuracy of predictions on post-discrimination generalization tests. Considering first response rates on generalization tests following wavelength discrimination* (Table 14, Appendix), the standard error for the Discrimination Hypothesis is 25.1, while the standard error for the Multiplicative Hypothesis is 10.4. In regard to the direction of prediction errors, 12 of the 16 mean response rates are underpredicted by the Discrimination Hypothesis, while only seven of the 16 mean response rates are underpredicted by the Multiplicative Hypothesis.

The 16 mean response rates to be predicted were divided into two groups: eight low response rates (response rates to 560 and 570 Mμ) and eight high response rates (response rates to 530 and 550 Mμ). For low response rates, the standard error for the Discrimination Hypothesis is 6.3, while the standard error for the Multiplicative Hypothesis is 6.0. It is noted that the value of the standard error for the Discrimination Hypothesis is much smaller than the value found in pre-discrimination generalization. This change can be accounted for by the fact that mean

*Predicted response rates were computed using 540 Mμ-90°, where the mean peak of responding was located, as the S^+. In computations of predicted response rates in other generalization tests, the mean peak of responding was located at the true S^+, 550 Mμ-90°.

obtained response rates to these stimuli are quite small (3.9) following wavelength discrimination, and mean response rates to these stimuli predicted by the Discrimination Hypothesis are all zero. While the Discrimination Hypothesis underpredicts six of the eight low response rates, the Multiplicative Hypothesis overpredicts seven of these eight response rates.

For high response rates, the standard error for the Discrimination Hypothesis is 139.9, and the standard error for the Multiplicative Hypothesis is 36.3. Thus, differences in overall predictions of the two hypotheses are accounted for in terms of predictions of high response rates. The Discrimination Hypothesis underpredicts six of these eight response rates, while the Multiplicative Hypothesis overpredicts five of these eight response rates.

On generalization tests following discrimination of angular orientation differences (Table 17, Appendix), the standard error for the Discrimination Hypothesis is 14.0, while the standard error for the Multiplicative Hypothesis is 10.2. The Discrimination Hypothesis underpredicts 15 of the 16 response rates, while the Multiplicative Hypothesis underpredicts only seven of the 16 response rates.

For the eight low response rates (response rates to stimuli including 30° and 150°), the standard error for the Discrimination Hypothesis is 2.5, while the standard error for the Multiplicative Hypothesis is .5. The small size of the standard error for the Discrimination Hypothesis is accounted for by the fact that mean obtained low

response rates are quite small (1.2), and mean response rates predicted by the Discrimination Hypothesis are all zero. While the Discrimination Hypothesis underpredicts seven of these eight mean response rates, the Multiplicative Hypothesis underpredicts only four of these eight response rates. For the eight high response rates (response rates to stimuli including 60° and 120°), the standard error for the Discrimination Hypothesis is 20.3, while the standard error for the Multiplicative Hypothesis is 14.8. The Discrimination Hypothesis underpredicts seven of these eight response rates, while the Multiplicative Hypothesis underpredicts only three of these eight response rates. Thus, predictions of high response rates for the most part account for differences in overall predictions of the two hypotheses.

On generalization tests following discrimination of wavelength and angular orientation differences (Table 20, Appendix), the standard error for the Discrimination Hypothesis is 24.2, while the standard error for the Multiplicative Hypothesis is 5.2. The Discrimination Hypothesis underpredicts 13 of the 16 mean response rates, while the Multiplicative Hypothesis overpredicts 13 of the 16 mean response rates.

The Discrimination Hypothesis predicts low mean response rates (response rates to stimuli including 30° and 150°) with a standard error of 1.9, while the Multiplicative Hypothesis predicts the same response rates with a standard error of 2.5. The very small standard error for the Discrimination Hypothesis is accounted for by the fact that, in every case, values predicted by this hypothesis are zero, and mean obtained

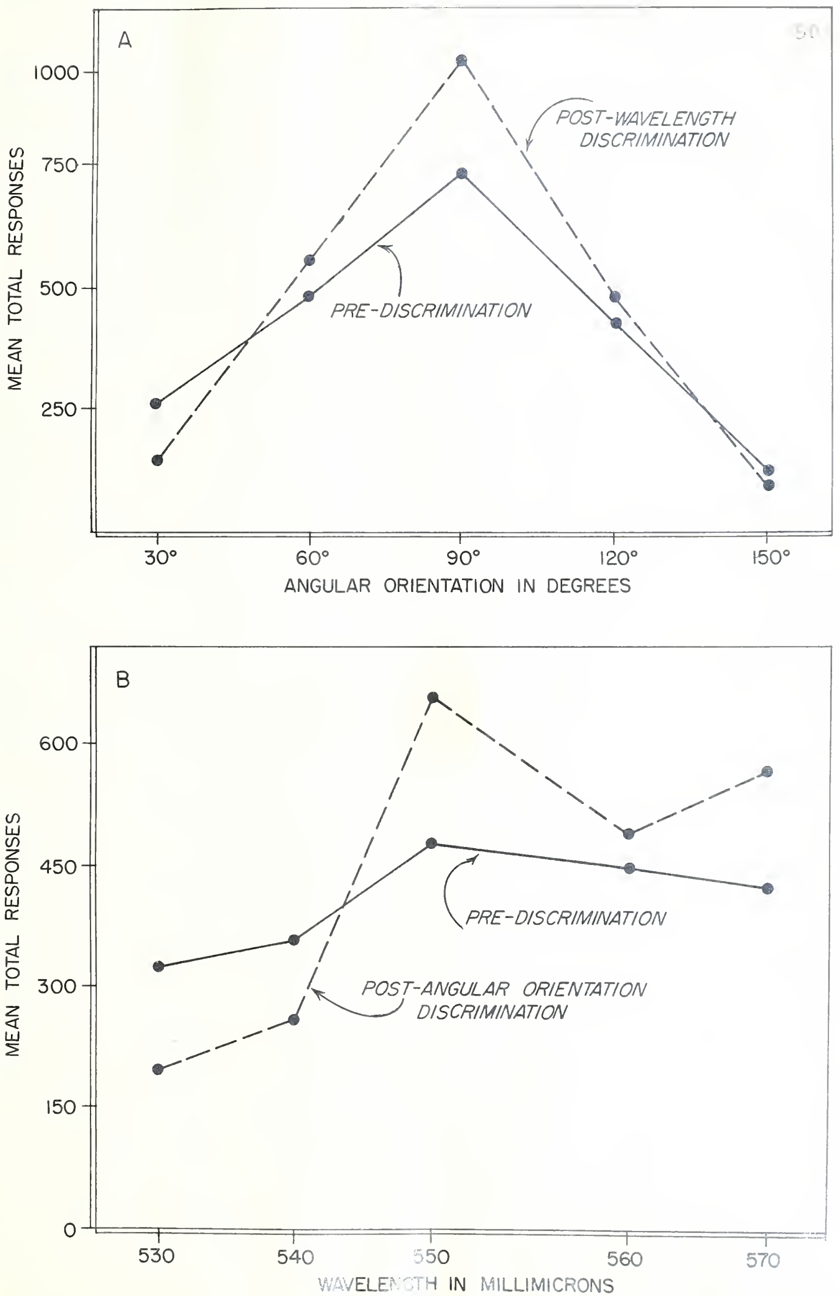
low response rates average .9. While the Discrimination Hypothesis underpredicts seven of these eight values, the Multiplicative Hypothesis overpredicts seven of the eight values.

The Discrimination Hypothesis predicts high mean response rates (response rates to stimuli including 60° and 120°) with a standard error of 35.6, while the Multiplicative Hypothesis predicts the same response rates with a standard error of 7.2. Thus, the smaller overall standard error for the Multiplicative Hypothesis is accounted for in terms of predicted high response rates. The Discrimination Hypothesis underpredicts all eight of these response rates, while the Multiplicative Hypothesis overpredicts six of the eight values.

<u>Changes in stimulus generalization along the undiscriminated dimension</u>: Changes in stimulus generalization gradients along previously discriminated dimensions have been described above. It is also possible to determine whether any changes take place in stimulus generalization along a previously undiscriminated dimension. In Fig. 12A, angular orientation generalization gradients before and after wavelength discrimination are compared. Both gradients contain mean total responses of Group TC-C Ss to angular orientation stimuli summed over all wavelength values. It is seen that following wavelength discrimination, the angular orientation gradient is raised at 90° and is steepened on both sides.

Wavelength generalization gradients before and after angular orientation discrimination are compared in Fig. 12B. Both gradients

Fig. 12. Generalization along previously undiscriminated dimensions. A. Angular orientation gradient before and after wavelength discrimination (Group TC-C). B. Wavelength gradient before and after angular orientation discrimination (Group TC-T).


A
MEAN TOTAL RESPONSES
1000
750
500
250
POST-WAVELENGTH DISCRIMINATION
PRE-DISCRIMINATION
30°
60°
90°
120°
150°
ANGULAR ORIENTATION IN DEGREES
B
MEAN TOTAL RESPONSES
600
450
300
150
0
PRE-DISCRIMINATION
POST-ANGULAR ORIENTATION DISCRIMINATION
530
540
550
560
570
WAVELENGTH IN MILLIMICRONS

contain mean total responses of Group TC-T Ss to wavelength stimuli summed over all angular orientation values. The wavelength gradient obtained following angular orientation discrimination is raised at 550 Mμ and is steeper than the pre-discrimination gradient at values below 550 Mμ and at 560 Mμ. At 570 Mμ, however, the post-discrimination gradient rises.

Chapter VI

DISCUSSION

The results of the first part of Experiment 3 provide a clear answer to the question of the difference between stimulus generalization along one and two dimensions. Mean response rates to stimuli differing to a specified extent along the wavelength and angular orientation dimensions were consistently less than mean response rates to stimuli differing to the same extent in each dimension alone. This finding is in agreement with the results of other studies of generalized instrumental responses to stimuli varying in one and two or more dimensions (Fink & Patton, 1953; White, 1958).

Concerning the second major aim of this study, a description of the quantitative relationship between response rates to stimuli varying in one and in two dimensions, the results of the first part of Experiment 3

are in closer agreement with the predictions of the Multiplicative Hypothesis than with predictions of the Discrimination Hypothesis, which underpredicted the majority of mean response rates.

It is evident that the Multiplicative Hypothesis not only leads to more accurate predictions than the Discrimination Hypothesis, but also that these predictions are quite accurate in absolute terms. In a range of response rates from 17 to 92, the overall standard error of the estimate computed from the Multiplicative Hypothesis was 9.4; and three-fourths of the predictions fall within this margin of error. This finding confirms the results of a previous exploratory study in which predictions of the Multiplicative Hypothesis were also in close agreement with obtained response rates (Butter & Guttman, 1958). Furthermore, the success of the Multiplicative Hypothesis' predictions strengthens the assumptions upon which the hypothesis is based, the most important of which is that the basic factor underlying stimulus generalization in two dimensions is an "observing response" rather than summated generalization decrements which operate independently of selection and observing activities. More specifically, it is assumed that S observes changes in the training stimulus and that the probability of such observations increases as the physical distance from the training stimulus increases along some specified dimension. When the stimulus is varied in more than one dimension, the probabilities of observing a stimulus change in each dimension alone can be combined as independent but not mutually exclusive events in order to determine the probability of observing stimulus changes

in both dimensions.

The validation of the Multiplicative Hypothesis suggests that the concept of an observing response may be applied to the analysis of stimulus generalization as well as discrimination learning (Wyckoff, 1952). Also the concept presented here is similar to that of V T E (Muenzinger & Gentry, 1931; Tolman, 1938) in respect to its function of "isolating" and selecting stimuli in the presence of which an appropriate response may be made. However, while the observing response and V T E behavior have been treated as empirical dependent variables, the concept presented in this study has the status of an intervening variable whose function is to explain generalization phenomena.

While the Multiplicative Hypothesis predicts response rates reasonably well and within smaller limits of error than does the Discrimination Hypothesis, other aspects of the predictions remain to be discussed. It was found that predictions of low response rates are less accurate than predictions of high response rates. This difference in predictions can be explained as an artifact of the method of multiplying response probabilities. Assuming that the measurement error is always the same for these response probabilities, then the error in the product of any two of them is proportional to the size of the probabilities which are multiplied. Thus, the product of large response probabilities will contain proportionally more error than the product of small response probabilities.

It was also found that the Multiplicative Hypothesis overpredicts three-fourths of high mean response rates. Although there is no reason-

able explanation for this fact, it suggests that the inverse relationship between probability of a pecking response and probability of an observing response is not linear but, rather, as the probability of an observing response decreases, the probability of a pecking response increases at a faster rate. Thus, for a given probability of pecking response, the probability of an observing response should be lower than is estimated by the assumed linear relationship between the two variables.

Comparison of generalization gradients obtained in Experiment 3 with those obtained in Experiments 1 and 2 discloses some effect of stimulus variation in one dimension on generalization in a second dimension. Response rates to wavelength stimuli were not changed by variations in angular orientation. However, response rates to two angular orientation stimuli (30° and 150°) were higher when variations in wavelength were present (Exp. 3) than when no wavelength variations were present (Exp. 1). This finding indicates that observing responses to stimuli changed in either dimension are not always independent, but that conditional probabilities of one observing response given a second observing response may have to be taken into consideration under some conditions. The above results suggest that observing responses having high probability (i.e., those resulting in low response rates) are more readily influenced by other observing responses. However, the Multiplicative Hypothesis' standard error for low response rates (response rates to stimuli including 30° and 150°) was quite small (2.7). It is thus unlikely that such conditional probabilities had a marked influence upon predictions.

Predictions of response rates in post-discrimination generalization were, in general, similar to those discussed above. All overall predictions of the Multiplicative Hypothesis were more accurate than those of the Discrimination Hypothesis, which underpredicted the majority of response rates. Also, the Multiplicative Hypothesis predicted low response rates with greater accuracy than it did high response rates, which are, for the most part, overpredicted.

However, in post-discrimination generalization, the greater accuracy of the Multiplicative Hypothesis' predictions is accounted for mainly by predictions of high response rates and not, as in pre-discrimination generalization, by predictions of low response rates. The lack of differential prediction errors for low response rates can be attributed to spuriously low standard errors for the Discrimination Hypothesis. Mean obtained low response rates are all extremely small, and mean response rates predicted by the Discrimination Hypothesis are in all instances zero. Thus, the Discrimination Hypothesis fails to make differential predictions of low response rates. Whenever the sum of generalization decrements to two single stimulus changes is 100% or more, the Discrimination Hypothesis predicts zero response rate to the combined double stimulus change.

The Multiplicative Hypothesis' overall standard error on generalization tests following wavelength discrimination was more than twice as large as its standard error on pre-discrimination generalization. This large standard error is due mainly to overpredictions of response rates to stimuli

including 550 Mμ. No satisfactory explanation for these large prediction errors is available. However, it should be noted that the peak shift from 550 to 540 Mμ following wavelength discrimination may be responsible for complicating predictions. The Multiplicative Hypothesis' predictions in other post-discrimination generalization tests were comparable in accuracy to predictions in pre-discrimination generalization.

The selectivity shown by Ss to discriminative stimuli is an interesting and significant fact. On generalization tests following wavelength-angular orientation discrimination training, there was much less response suppression to the wavelength component S^- than there was to the angular orientation component S^-. Following wavelength discrimination training, response suppression to the same wavelength S^- alone was much greater. These results support an observing response analysis which assumes that discriminable differences in stimuli do not necessarily affect Ss' response rates equally, but that Ss actively select and observe some stimulus differences more than others. Other evidence for the selectivity of stimuli in discrimination training is given by Warren (1954). In this study, monkeys were trained to discriminate objects differing in form, color and size. Performance in subsequent tests was worse when color differences were eliminated than when size or form differences between objects were eliminated. The results of the present study suggest that the selection of discriminative stimuli is determined by the amount of generalization decrement between the stimuli in prior generalization testing. The generalization decrement between angular orientation stimuli employed in discrimin-

ation training was significantly greater than the generalization decrement between wavelength stimuli employed in discrimination training.

The finding that discrimination learning involving stimuli differing in two dimensions was faster than discrimination learning involving stimuli differing in each dimension alone is in agreement with the results of several past experiments (Harlow, 1945; Eninger, 1952; Warren, 1953). Since the physical differences between discriminative stimuli were not varied, it is not possible to determine the range of stimuli over which the addition of stimulus differences facilitates learning.

Changes in wavelength generalization gradients following wavelength discrimination training are similar to those reported in a previous study using a fully illuminated key (Hanson, 1956). Response rates in the region of the S^- are suppressed, the slope between S^+ and S^- is steepened, and responding is displaced to wavelength stimuli to the side of S^+ opposite S^-. Hanson's function relating modal peak displacement to $S^+ - S^-$ difference predicts a peak displacement of approximately 11 Mμ for the $S^+ - S^-$ difference used in the present study. The modal peak displacement obtained in the present study was 10 Mμ. It is thus interesting to note that when the total area of the monochromatic light is reduced by approximately 90%, post-discrimination generalization gradients are not markedly changed. However, it was also found that the wavelength generalization gradient obtained in Experiment I had a broader slope than the wavelength gradient obtained with the full key illuminated by monochromatic light (Honig, Thomas & King, in press). In terms of the analysis of stimulus

generalization presented previously, this result suggests that the total area of the external stimulus is a variable which determines the probability of an observing response following single stimulus training. Under these conditions, when the total area of the external stimulus is reduced, the probability of an observing response decreases, and a broader generalization gradient is obtained.

Angular orientation generalization gradients following discrimination of angular orientation stimuli are similar to those reported previously in an experiment using a band of white light (Butter & Guttman, 1957). There is marked response suppression in the region of the S^-, the slope between S^+ and S^- is steepened, and responding is displaced to stimuli away from the S^-.

It was also found that generalization gradients along one dimension are raised at the peak and steepened following discrimination training between stimuli differing along a second dimension. This finding is open to two interpretations. These changes in generalization may be attributed to the effects of prior discrimination training. This interpretation is consistent with Reinhold and Perkin's (1955) finding that the slope of a generalization gradient along one dimension is steepened following discrimination training between stimuli differing along a second dimension. On the other hand, the generalization changes found in the present study may be a consequence of discriminations developed along the same dimension in prior generalization testing. Since the present study did not include controls for the possible effects of this factor, it is not possible to decide between these two alternatives.

Chapter VII

SUMMARY AND CONCLUSIONS

The purpose of this study was (1) to compare response rates to stimuli differing from the training stimulus in one and in two dimensions and (2) to describe the quantitative relationship between response rates to these two kinds of stimuli. Two alternative hypotheses concerning this quantitative relationship are presented. The first, the Discrimination Hypothesis, assumes that when a stimulus is changed in two dimensions the number of j. n. d. steps taken in each dimension alone are added. This hypothesis predicts that the generalization decrement resulting from a stimulus changed in two dimensions equals the sum of generalization decrements in each dimension alone. The second hypothesis, the

Multiplicative Hypothesis, assumes that observing responses are made to stimuli changed by some discriminable amount. By combining probabilities of observing responses to stimuli changed in each dimension alone, the Multiplicative Hypothesis predicts that the probability of a pecking response to a stimulus changed in both dimensions is the product of pecking response probabilities to stimuli changed in each dimension alone.

The Ss, 27 White Carneau pigeons, were trained to peck at a key illuminated by a narrow band of monochromatic light. In subsequent generalization tests, Ss were presented with all combinations of five values of wavelength and five values of angular orientation of the band of light (Exp. 3).

Mean response rates to stimuli differing in both dimensions from the training stimulus were consistently lower than mean response rates to stimuli differing in each dimension alone. This finding is consistent with the results of past experiments of stimulus generalization in one and several dimensions (Fink & Patton, 1953; White, 1958).

The Multiplicative Hypothesis predicted response rates to stimuli varying in two dimensions with a fairly high degree of accuracy, while predictions of the Discrimination Hypothesis showed larger errors. It was also found that the majority of Multiplicative Hypothesis' prediction errors were overpredictions. This finding suggests that the assumed relationship between observing response probability and pecking response probability is incorrect, and appropriate changes in the relationship were

suggested. Standard errors of the Multiplicative Hypothesis' predictions were larger for high response rates than for low response rates. This finding was explained as an artifact of the method of computing predictions.

Two control experiments were performed in order to determine whether response rates to stimuli changed in one dimension are changed by variations in a second dimension. In Experiment 1, a wavelength generalization gradient obtained with constant angular orientation was described, and in Experiment 2, an angular orientation generalization gradient with constant wavelength was described. Comparison of these two gradients with comparable gradients obtained in Experiment 3 discloses that mean response rates to two angular orientation stimuli (30° and 150°) are higher when wavelength variations are also present. This finding indicates that, under some conditions, observing responses are not independent.

In addition, the wavelength generalization gradient obtained in Experiment 1 had a broader slope than a wavelength gradient obtained with the full key illuminated with monochromatic light (Honig, Thomas & King, in press). This finding was interpreted in terms of the effect of total area of the external stimulus on the probability of an observing response.

Following the completion of generalization testing, Ss in Experiment 3 were divided into three groups. One group was given discrimination training involving stimuli differing in wavelength, a second group was given discrimination training involving stimuli differing in angular

orientation, and the third group was given discrimination training involving stimuli differing in both dimensions. Discrimination learning involving stimuli differing in both dimensions was faster than discrimination learning involving stimuli differing in either dimension alone. This finding is consistent with the results of several past experiments (Harlow, 1945; Eninger, 1952; Warren, 1953).

Following discrimination training, all Ss were tested for stimulus generalization in the same manner as described previously. Predictions of mean response rates on post-discrimination generalization tests were similar to those described in pre-discrimination generalization tests. Also, the Multiplicative Hypothesis predicted low response rates with greater accuracy than it did high response rates. However, the Multiplicative Hypothesis' overall standard error on generalization tests following wavelength discrimination training was much larger than its standard error in pre-discrimination generalization. It was suggested that the peak shift in generalization gradients following wavelength discrimination may have complicated predictions.

The results of generalization testing following wavelength-angular orientation discrimination training indicate that Ss actively select some stimulus differences more readily than others in discrimination training. This finding is consistent with the observing response analysis presented previously. The results also suggest that the selection of discriminative stimuli is determined by the amount of generalization decrement between the stimuli.

Generalization gradients along the dimensions on which stimuli were previously discriminated were similar to those reported previously (Hanson, 1956; Butter & Guttman, 1957). Generalization gradients along previously undiscriminated dimensions were raised at the peak and steepened at most stimulus values. Lack of appropriate controls, however, made it impossible to determine the factor responsible for these changes.

It is concluded that response rates to stimuli varied in two dimensions are consistently lower than response rates to stimuli varied in only one dimension. Furthermore, the Multiplicative Hypothesis predicts quantitative relationships between response rates under these two sets of conditions reasonably well. The validation of the Multiplicative Hypothesis supports the assumption that a basic factor underlying stimulus generalization is an observing response by means of which Ss selectively "attend to" stimuli changed by some discriminable amount. It is thus possible to extend the observing response and similar concepts proposed within the context of discrimination learning (Muenzinger & Gentry, 1931; Tolman, 1938; Wyckoff, 1952) to stimulus generalization phenomena.

However, the results of this study indicate that two specific assumptions of the Multiplicative Hypothesis may be incorrect. It was suggested that the function relating probability of pecking response to probability of observing response is a negatively accelerated decreasing one, rather than the assumed linear one. Also, the assumption of independence of observing response probabilities must be qualified, at least

under some conditions, and conditional probabilities of one observing response given a second observing response may have to be taken into consideration.

The predictions of the Multiplicative Hypothesis are also applicable to generalization in two dimensions following discrimination training. However, when discrimination training results in marked shifts in the distribution of response rates, predictions of the Multiplicative Hypothesis are much less accurate.

The observing response analysis is also applicable to discrimination learning involving stimuli differing in two dimensions. Ss' selection of stimuli under these conditions appears to be a function of prior generalization decrement between stimuli. Furthermore, the effects of reducing the size of the stimulus in single stimulus training and generalization testing can be interpreted in terms of the observing response analysis. Following discrimination training, however, this variable appears to have little or no effect on stimulus generalization. It is also concluded that discrimination learning is faster when the stimuli differ in two dimensions than when they differ in each dimension alone.

APPENDIX

Table 1

Number of Responses to Different Stimuli in Corrected Group C Test

	Wavelength in Mμ									
Subject	490	510	520	538.5*	550	560	570	580	590	610
C-4	237	175	239	311	415	329	322	317	242	123
C-5	17	49	54	123	148	128	137	123	197	29
C-6	53	80	99	167	221	206	135	152	162	58
C-7	34	12	19	113	143	140	137	105	52	19
C-8	138	173	190	273	280	312	250	247	244	66
C-9	209	280	285	385	429	357	394	372	396	165
Total	688	769	886	1372	1636	1472	1375	1316	1293	460
Mean	114.7	128.2	147.7	228.7	272.7	245.3	229.2	219.3	215.5	76.7

*Response values for this stimulus point were obtained by averaging responses of individual Ss to 530 Mμ (actual value, 538 Mμ) and to 540 Mμ (actual value, 539 Mμ).

Table 2

Number of Responses to Different Stimuli in Corrected Group C Retest

	Wavelength in Mμ									
Subject	490	510	520	538.5*	550	560	570	580	590	610
C-4	2	0	0	18	24	13	5	6	12	0
C-5	6	11	9	37	49	73	47	53	67	8
C-6	0	0	1	3	14	17	5	1	0	0
C-7	1	0	3	29	113	88	45	16	0	2
C-8	7	3	5	20	10	19	20	8	1	0
C-9	44	79	38	167	240	214	128	132	148	17
Total	60	93	56	274	450	424	250	216	228	27
Mean	10.0	31.0	9.3	45.7	75.0	70.7	41.7	36.0	38.0	4.5

*Response values for this stimulus point were obtained by averaging responses of individual Ss to 530 Mμ (actual value, 538 Mμ) and to 540 Mμ (actual value, 539 Mμ).

Table 3

Number of Responses to Different Stimuli on Group T Test

	Angular orientation in degrees										
Subject	15	30	45	60	75	90	105	120	135	150	165
T-1	155	177	221	295	268	297	291	263	203	181	145
T-2	11	44	107	137	145	119	77	89	37	23	4
T-3	78	121	305	440	364	356	437	268	120	53	57
T-4	58	153	136	199	342	429	462	389	219	209	140
T-5	23	28	54	72	78	87	105	97	57	41	16
T-6	10	38	68	82	117	185	144	169	73	47	20
T-7	95	94	214	223	286	313	224	261	146	87	90
T-8	152	117	135	259	181	330	359	311	256	307	205
T-9	79	92	146	220	249	277	258	235	149	98	80
Total	661	864	1386	1927	2030	2393	2357	2082	1250	1046	757
Mean	73.4	96.0	154.0	214.1	225.6	265.9	261.9	231.3	138.9	116.2	84.1

Table 4

Number of Responses to Different Stimuli on Group T Retest

Subject	Angular orientation in degrees										
	15	30	45	60	75	90	105	120	135	150	165
T-1	1	7	3	26	33	24	47	17	18	3	0
T-2	0	0	0	9	39	22	12	0	0	0	0
T-3	0	0	0	0	0	0	0	0	0	0	0
T-4	1	3	20	37	180	230	226	88	41	3	2
T-5	0	0	3	3	6	19	20	1	0	0	0
T-6	0	0	3	31	21	63	35	40	11	0	1
T-7	0	27	58	116	109	135	163	85	62	19	0
T-8	4	0	20	20	10	79	93	31	4	10	2
T-9	0	6	11	24	53	68	61	28	19	6	1
Total	6	43	118	266	451	640	657	290	155	41	6
Mean	.7	4.8	13.1	29.6	50.1	71.1	73.0	32.2	17.2	4.6	.7

Table 5

Number of Responses to Different Stimuli on Group TC Test
(Wavelength in $M\mu$ - Angular orientation in degrees)

	$M\mu = 530$					$M\mu = 540$				
Subject	30°	60°	90°	120°	150°	30°	60°	90°	120°	150°
TC-120	60	19	65	41	24	47	39	31	37	45
TC-122	0	3	23	1	1	1	4	37	1	0
TC-123	41	14	18	31	5	66	95	83	132	47
TC-124	39	50	135	66	47	35	32	96	39	17
TC-125	11	0	69	24	0	16	0	0	20	2
TC-126	27	48	46	13	26	46	57	74	52	18
TC-127	3	10	65	22	7	5	28	105	14	8
TC-129	26	36	84	32	16	8	51	66	37	3
TC-130	128	193	240	135	59	84	144	157	178	42
TC-131	0	27	98	105	36	1	39	70	92	48
TC-132	6	24	15	18	5	11	73	26	36	5
TC-133	21	51	40	23	0	8	28	31	35	11
TC-134	25	81	97	41	11	5	67	46	28	0
TC-135	0	81	86	72	12	0	13	100	51	0
TC-136	4	53	187	164	0	13	56	245	175	1
TC-137	4	26	50	6	0	5	37	85	20	3
TC-138	86	78	72	28	22	76	75	66	99	54
TC-139	25	89	164	215	12	4	141	60	194	10
TC-140	11	19	141	174	85	28	37	96	211	99
TC-141	13	28	52	46	13	22	54	107	13	16

(continued)

Table 5 (continued)

Number of Responses to Different Stimuli on Group TC Test
(Wavelength in Mμ - Angular orientation in degrees)

	Mμ = 530 (continued)					Mμ = 540 (continued)				
Subject	30°	60°	90°	120°	150°	30°	60°	90°	120°	150°
TC-142	0	0	0	0	0	0	0	6	0	0
TC-143	8	90	127	84	12	6	90	145	90	6
TC-144	1	25	181	87	10	0	9	82	110	13
TC-145	0	118	244	54	0	13	94	280	14	0
TC-146	0	44	76	62	0	7	29	106	47	30
TC-147	6	19	41	27	30	21	18	38	48	24
TC-148	0	69	97	85	16	2	20	81	28	7
Total	545	1295	2513	1656	449	530	1330	2319	1801	509
Mean	20.2	48.0	93.1	61.3	16.6	19.6	49.3	85.9	66.7	18.8

(continued)

Table 5 (continued)

Number of Responses to Different Stimuli on Group TC Test
(Wavelength in Mμ - Angular orientation in degrees)

	Mμ = 550					Mμ = 550				
Subject	30°	60°	90°	120°	150°	30°	60°	90°	120°	150°
TC-120	32	77	116	73	56	62	71	95	36	176
TC-122	2	12	76	14	0	2	15	50	4	0
TC-123	84	98	77	117	79	51	99	111	74	52
TC-124	42	93	171	15	10	76	128	133	47	28
TC-125	0	99	47	67	16	32	0	81	69	0
TC-126	146	158	156	230	90	84	114	197	146	32
TC-127	11	59	182	44	0	4	61	132	47	0
TC-129	11	61	84	46	14	7	34	82	81	15
TC-130	143	308	354	311	35	393	409	437	197	63
TC-131	30	50	108	111	43	19	69	100	84	23
TC-132	17	46	21	19	11	5	41	27	27	0
TC-133	25	33	48	22	26	4	25	38	18	12
TC-134	105	81	107	44	26	46	0	54	11	19
TC-135	0	166	178	84	20	2	68	246	204	42
TC-136	7	150	252	211	1	2	92	224	81	1
TC-137	13	70	90	23	0	11	74	110	22	3
TC-138	88	215	147	63	75	36	83	91	72	46
TC-139	56	136	123	155	21	42	288	139	117	44
TC-140	12	7	216	183	67	3	3	170	190	56
TC-141	4	35	184	51	4	5	32	133	85	25

(continued)

Table 5 (continued)

Number of Responses to Different Stimuli on Group TC Test
(Wavelength in $M\mu$ - Angular orientation in degrees)

Subject	$M\mu$ = 550 (continued) 30°	60°	90°	120°	150°	$M\mu$ = 560 (continued) 30°	60°	90°	120°	150°
TC-142	79	125	154	169	148	24	21	66	2	13
TC-143	2	187	183	107	9	12	140	188	139	39
TC-144	12	45	144	171	15	0	9	107	102	7
TC-145	41	164	118	72	5	11	314	174	37	0
TC-146	0	67	151	103	18	2	66	100	78	2
TC-147	41	48	68	95	27	49	56	106	85	54
TC-148	36	115	179	93	6	40	55	140	68	1
Total	1039	2705	3734	2693	822	1024	2367	3531	2123	753
Mean	38.5	100.2	138.4	99.7	30.4	37.9	87.7	130.8	78.6	27.9

(continued)

Table 5 (continued)

Number of Responses to Different Stimuli on Group TC Test
(Wavelength in Mμ - Angular orientation in degrees)

	Mμ = 570				
Subject	30°	60°	90°	120°	150°
TC-120	21	64	64	79	98
TC-122	0	7	61	2	1
TC-123	55	95	118	110	102
TC-124	65	110	101	38	4
TC-125	43	68	80	0	3
TC-126	151	169	211	131	44
TC-127	4	49	96	9	0
TC-129	8	54	92	89	35
TC-130	243	252	496	137	99
TC-131	21	56	130	77	18
TC-132	0	19	49	4	1
TC-133	9	16	15	22	4
TC-134	0	49	36	29	9
TC-135	1	36	175	72	1
TC-136	3	86	179	107	2
TC-137	3	72	76	22	0
TC-138	58	99	108	147	52
TC-139	26	173	265	158	32
TC-140	4	12	119	95	37
TC-141	2	68	97	47	12

(continued)

Table 5 (continued)

Number of Responses to Different Stimuli on Group TC Test
(Wavelength in Mμ - Angular orientation in degrees)

	Mμ = 570 (continued)				
Subject	30^{o}	60^{o}	90^{o}	120^{o}	150^{o}
TC-142	0	10	33	3	1
TC-143	0	155	185	135	42
TC-144	0	45	137	50	0
TC-145	0	196	74	6	0
TC-146	0	52	150	64	28
TC-147	39	73	78	68	56
TC-148	22	54	188	92	13
Total	778	2139	3413	1793	694
Mean	28.8	79.2	126.4	66.4	25.7

Table 6

Number of Responses to Different Stimuli on Group TC Retest
(Wave length in $M\mu$ - Angular orientation in degrees)

	$M\mu = 530$					$M\mu = 540$				
Subject	30°	60°	90°	120°	150°	30°	60°	90°	120°	150°
TC-120	10	39	14	23	9	3	27	8	19	30
TC-122	0	0	0	0	0	0	0	2	0	0
TC-123	0	0	55	28	0	11	0	0	31	7
TC-124	0	0	3	0	0	0	3	2	0	8
TC-125	0	4	25	15	0	0	0	0	19	11
TC-126	0	0	0	0	0	4	0	0	4	0
TC-127	0	0	8	0	0	0	0	40	0	3
TC-129	0	5	23	1	0	0	1	3	1	0
TC-130	0	21	18	2	0	43	19	3	8	0
TC-131	0	0	14	0	0	0	2	1	0	0
TC-132	4	0	8	1	0	0	27	6	5	0
TC-133	5	0	8	6	0	0	0	10	11	1
TC-134	10	4	0	0	1	6	0	6	0	0
TC-135	1	7	5	0	0	0	7	14	3	0
TC-136	0	0	2	0	0	0	0	1	0	0
TC-137	0	5	0	0	0	0	0	0	0	0
TC-138	0	16	12	2	0	0	2	2	0	0
TC-139	0	0	25	39	0	0	19	58	6	0
TC-140	0	0	0	14	0	0	1	15	14	0
TC-141	0	7	27	0	0	0	2	0	30	2

(continued)

Table 6 (continued)

Number of Responses to Different Stimuli on Group TC Retest
(Wavelength in $M\mu$ - Angular orientation in degrees)

Subject	$M\mu = 530$ (continued)					$M\mu = 540$ (continued)				
	30°	60°	90°	120°	150°	30°	60°	90°	120°	150°
TC-142	0	0	0	0	0	0	0	0	0	0
TC-143	0	0	3	0	0	0	0	0	0	0
TC-144	0	1	18	12	0	0	0	1	7	0
TC-145	0	33	99	12	0	0	112	103	18	0
TC-146	0	0	0	1	0	0	0	13	1	0
TC-147	0	0	1	0	0	0	0	6	0	0
TC-148	0	1	10	0	0	0	2	0	0	0
Total	30	143	378	156	10	67	224	294	177	62
Mean	1.1	5.3	14.0	5.8	.4	2.5	8.3	10.9	6.6	2.3

(continued)

Table 6 (continued)

Number of Responses to Different Stimuli on Group TC Retest
(Wavelength in Mμ - Angular orientation in degrees)

	Mμ = 550					Mμ = 560				
Subject	30°	60°	90°	120°	150°	30°	60°	90°	120°	150°
TC-120	0	16	25	41	32	14	18	14	15	11
TC-122	0	0	12	0	0	0	0	0	0	0
TC-123	0	17	96	79	3	16	29	34	61	0
TC-124	4	9	3	6	0	1	4	6	7	2
TC-125	7	42	43	0	0	0	0	53	2	0
TC-126	0	4	9	6	0	0	0	0	0	0
TC-127	0	31	1	0	2	0	11	0	0	0
TC-129	0	6	0	0	0	2	0	7	5	0
TC-130	18	98	59	9	0	11	34	0	1	0
TC-131	0	0	1	0	0	0	1	23	9	0
TC-132	0	25	11	7	1	0	13	3	1	0
TC-133	2	22	11	0	0	0	6	1	5	0
TC-134	1	47	7	0	0	6	55	17	3	0
TC-135	1	0	4	19	0	0	7	44	10	0
TC-136	0	0	0	0	0	0	0	0	1	0
TC-137	0	0	3	0	0	0	0	0	0	0
TC-138	0	6	7	0	0	1	3	6	0	0
TC-139	0	16	59	55	0	2	35	44	65	0
TC-140	0	0	48	12	16	0	0	8	9	2
TC-141	0	0	32	16	1	0	0	0	18	0

(continued)

Table 6 (continued)

Number of Responses to Different Stimuli on Group TC Retest
(Wavelength in $M\mu$ - Angular orientation in degrees)

Subject	$M\mu$ = 550 (continued)					$M\mu$ = 560 (continued)				
	30°	60°	90°	120°	150°	30°	60°	90°	120°	150°
TC-142	0	26	65	54	60	1	1	0	8	0
TC-143	0	2	9	24	3	0	0	21	0	0
TC-144	0	0	43	0	0	0	0	4	18	0
TC-145	0	26	92	20	0	0	48	92	24	0
TC-146	0	0	19	5	0	0	0	0	0	0
TC-147	0	1	3	0	0	0	0	24	11	0
TC-148	0	1	5	3	0	0	6	63	12	0
Total	33	395	667	356	118	54	271	464	285	15
Mean	1.2	14.6	24.7	13.2	4.4	2.0	10.0	17.2	10.6	.6

(continued)

Table 6 (continued)

Number of Responses to Different Stimuli on Group TC Retest
(Wavelength in $M\mu$ - Angular orientation in degrees)

	$M\mu$ = 570				
Subject	30°	60°	90°	120°	150°
TC-120	22	22	11	30	2
TC-122	0	0	2	0	1
TC-123	3	18	0	41	30
TC-124	7	3	17	16	2
TC-125	0	47	48	0	0
TC-126	0	51	0	0	0
TC-127	0	0	1	0	0
TC-129	0	1	11	9	0
TC-130	0	11	44	11	0
TC-131	0	4	11	0	0
TC-132	2	5	12	0	1
TC-133	0	0	0	0	1
TC-134	10	35	18	0	4
TC-135	0	8	45	27	0
TC-136	0	0	2	0	0
TC-137	0	0	1	0	0
TC-138	0	0	2	0	0
TC-139	0	3	62	20	0
TC-140	0	0	9	9	0
TC-141	0	0	38	0	0

(continued)

Table 6 (continued)

Number of Responses to Different Stimuli on Group TC Retest
(Wavelength in Mu - Angular orientation in degrees)

	Mμ = 570 (continued)				
Subject	30°	60°	90°	120°	150°
TC-142	1	0	1	0	0
TC-143	0	13	52	40	0
TC-144	0	0	4	34	0
TC-145	0	0	101	7	0
TC-146	0	0	0	0	0
TC-147	0	15	4	0	0
TC-148	0	35	0	14	0
Total	45	271	496	258	41
Mean	1.7	10.0	18.4	9.6	1.5

Table 7

Differences between Mean Log Responses of Group TC
to Stimuli Varying in One and in Two Dimensions

Stimuli	Mean log responses	t^1	Stimuli	Mean log responses	t
530 Mμ-30°	.926		560 Mμ-30°	1.164	3.34^2
vs.		6.72^2	vs.		
530 Mμ-90°	1.893		560 Mμ-90°	2.106	
530 Mμ-30°	.926		560-Mμ-30°	1.164	
vs.		3.34^2	vs.		2.14^2
550 Mμ-30°	1.309		550 Mμ-30°	1.309	
530 Mμ-60°	1.535		560 Mμ-60°	1.711	
vs.		5.77^2	vs.		2.63^2
530 Mμ-90°	1.893		560 Mμ-90°	2.106	
530 Mμ-60°	1.535		560 Mμ-60°	1.711	
vs.		2.54^2	vs.		2.66^2
550 Mμ-60°	1.948		550 Mμ-60°	1.948	
530 Mμ-120°	1.616		560 Mμ-120°	1.825	
vs.		4.92^2	vs.		4.90^2
530 Mμ-90°	1.893		560 Mμ-90°	2.106	
530 Mμ-120°	1.616		560 Mμ-120°	1.825	
vs.		2.65^2	vs.		2.92^2
550 Mμ-120°	1.931		550 Mμ-120°	1.931	

Table 7 (continued)
Differences between Mean Log Responses of Group TC
to Stimuli Varying in One and in Two Dimensions

Stimuli	Mean log responses	t[1]	Stimuli	Mean log responses	t
530 Mμ-150° vs. 530 Mμ-90°	.909 1.893	3.43[2]	560 Mμ-150° vs. 560 Mμ-90°	1.079 2.106	7.81[2]
530 Mμ-150° vs. 550 Mμ-150°	.909 1.256	2.81[2]	560 Mμ-150° vs. 550 Mμ-150°	1.079 1.256	1.94[3]
540 Mμ-30° vs. 540 Mμ-90°	1.026 1.833	3.83[2]	570 Mμ-30° vs. 570 Mμ-90°	.977 2.188	7.71[2]
540 Mμ-30° vs. 550 Mμ-30°	1.026 1.309	4.12[2]	570 Mμ-30° vs. 550 Mμ-30°	.977 1.309	3.07[2]
540 Mμ-60° vs. 540 Mμ-90°	1.542 1.833	1.89[3]	570 Mμ-60° vs. 570 Mμ-90°	1.818 2.188	4.75[2]
540 Mμ-60° vs. 550 Mμ-60°	1.542 1.946	3.56[2]	570 Mμ-60° vs. 550 Mμ-60°	1.818 1.948	2.31[2]
540 Mμ-120° vs. 540 Mμ-90°	1.667 1.833	2.85[2]	570 Mμ-120° vs. 570 Mμ-90°	1.640 2.188	3.04[2]

Table 7 (continued)

Differences between Mean Log Responses of Group TC to Stimuli Varying in One and in Two Dimensions

Stimuli	Mean log responses	t^1	Stimuli	Mean log responses	t
540 Mμ-120°	1.667		570 Mμ-120°	1.640	
vs.		2.82^2	vs.		3.25^2
550 Mμ-120°	1.931		550 Mμ-120°	1.931	
540 Mμ-150°	1.001		570 Mμ-150°	1.034	
vs.		4.04^2	vs.		7.36^2
540 Mμ-90°	1.833		570 Mμ-90°	2.188	
540 Mμ-150°	1.001		570 Mμ-150°	1.034	
vs.		2.44^2	vs.		2.73^2
550 Mμ-150°	1.256		550 Mμ-150°	1.256	

1. df = 26 for all tests.

2. $p < .05$.

3. $.05 < p < .1$.

Table 8

Mean Predicted and Obtained Responses of Group TC on Generalization Tests

Stimulus	Mean obtained responses	Mean responses predicted by Discrimination Hypothesis	Deviation of predicted from obtained	Mean responses predicted by Multiplicative Hypothesis	Deviation of predicted from obtained
530 Mμ 30°	21.3	0.0	21.3	26.0	4.7
530 Mμ 60°	56.3	58.6	5.4	75.3	22.0
530 Mμ 120°	67.1	57.8	9.3	74.7	7.6
530 Mμ 150°	17.0	0.0	17.0	24.0	7.0
540 Mμ 30°	22.1	0.0	22.1	23.5	1.4
540 Mμ 60°	57.6	48.3	9.2	68.1	10.5
540 Mμ 120°	73.3	47.5	25.3	67.6	5.7
540 Mμ 150°	21.5	0.0	21.5	21.7	.2

(continued)

Table 8 (continued)

Mean Predicted and Obtained Responses of Group TC on Generalization Tests

Stimulus	Mean obtained responses	Mean responses predicted by Discrimination Hypothesis	Deviation of predicted from obtained	Mean responses predicted by Multiplicative Hypothesis	Deviation of predicted from obtained
560 Mμ 30°	38.5	25.6	12.9	36.3	2.2
560 Mμ 60°	87.2	100.7	13.5	104.9	17.2
560 Mμ 120°	91.9	99.8	7.9	104.1	12.2
560 Mμ 150°	28.9	22.4	6.5	33.4	4.5
570 Mμ 30°	30.5	0.0	30.5	27.9	2.6
570 Mμ 60°	89.3	66.3	22.9	80.7	8.5
570 Mμ 120°	76.0	65.5	10.5	80.1	4.2
570 Mμ 150°	27.2	0.0	27.2	25.7	1.5
Standard error (overall)			17.3		9.4
Standard error (30°, 150°)			15.3		9.0
Standard error (60°, 120°)			10.7		2.7

Table 9

Comparison between Mean Responses of Groups C and TC to Wavelength Stimuli

	Mean total responses			
Wavelength in Mμ	Group C test	Group TC test and retest[1] (angular orientation = 90°)	t	df
540	186.9	206.2	.43[2]	7
560	245.3	258.5	.30[2]	8
570	229.2	224.2	.48[2]	8

1. Responses of Ss in Group TC were raised by a constant amount to match their mean peak of responding at 550 Mμ - 90° to that of Ss in Group C.

2. $p > .75$.

Table 10

Comparison between Mean Responses of Groups T and TC to Angular Orientation Stimuli

Angular orientation in degrees	Mean total responses: Group T test	Mean total responses: Group TC test and retest [1] ($M\mu = 550$)	t	df
30	96.0	142.3	2.40[2]	13
60	214.1	217.4	.08[3]	12
120	231.3	216.5	.41[3]	13
150	116.2	139.2	2.20[2]	10

1. Responses of Ss in Group TC were raised by a constant amount to match their mean peak of responding at 550 $M\mu$ - 90° to that of Ss in Group T.

2. $p < .05$.

3. $p > .75$.

Table 11

Comparison of Number of Days to Discrimination Criterion for Three Discrimination Groups (Mann-Whitney *U* Tests)

Subject	Days to criterion: Wavelength discrimination group	Subject	Days to criterion: Angular orientation discrimination group	Subject	Days to criterion: Wavelength-angular orientation discrimination group
TC-C-124	16.9	TC-T-122	19.9	TC-TC-120	15.0
TC-C-126	30.0	TC-T-123	30.0	TC-TC-125	8.5
TC-C-130	14.0	TC-T-129	17.0	TC-TC-127	13.8
TC-C-133	15.0	TC-T-135	12.0	TC-TC-131	6.7
TC-C-134	9.0	TC-T-138	11.2	TC-TC-132	7.7
TC-C-136	11.0	TC-T-139	11.0	TC-TC-137	5.8
TC-C-142	.7	TC-T-140	15.7	TC-TC-141	11.0
TC-C-146	13.8	TC-T-143	13.9	TC-TC-144	7.7
TC-C-148	21.9	TC-T-145	25.0	TC-TC-147	5.0
Mean	14.7		17.3		9.0
Median	14.0		15.7		7.7

Wavelength discrimination vs. wavelength-angular orientation discrimination

$U = 18.5 \quad .05 < p < .1$

Angular orientation discrimination vs. wavelength-angular orientation discrimination

$U = 8.5 \quad .002 < p < .02$

Wavelength discrimination vs. angular orientation discrimination

$U = 32.5 \quad p > .1$

Table 12

Number of Responses to Different Stimuli on Test Following Wavelength Discrimination
(Wavelength in Mμ - Angular orientation in degrees)

	Mμ = 530					Mμ = 540				
Subject	30°	60°	90°	120°	150°	30°	60°	90°	120°	150°
TC-C-124	2	271	497	452	1	0	340	722	601	2
TC-C-126	350	479	474	473	44	506	632	550	609	50
TC-C-130	75	275	330	180	40	16	425	492	367	43
TC-C-133	0	15	64	7	1	2	61	110	38	0
TC-C-134	10	52	82	20	0	27	50	172	171	10
TC-C-136	15	350	561	115	1	42	464	674	88	1
TC-C-142	0	0	0	0	0	0	0	0	0	0
TC-C-146	0	0	20	0	0	0	0	79	0	0
TC-C-148	33	102	191	130	102	10	109	309	291	58
Total	485	1544	2219	1377	189	603	2081	3108	2165	164
Mean	53.9	171.6	246.6	153.0	21.0	67.0	231.2	345.3	240.6	18.2

(continued)

Table 12 (continued)

Number of Responses to Different Stimuli on Test Following Wavelength Discrimination
(Wavelength in Mμ - Angular orientation in degrees)

	Mμ = 550					Mμ = 560				
Subject	30°	60°	90°	120°	150°	30°	60°	90°	120°	150°
TC-C-124	0	175	744	270	0	0	0	0	0	0
TC-C-126	2	293	133	113	38	1	40	0	1	0
TC-C-130	0	173	144	46	86	5	0	0	0	0
TC-C-133	3	17	49	12	0	0	0	8	0	0
TC-C-134	1	86	242	122	29	0	28	144	1	4
TC-C-136	4	40	340	86	0	0	0	6	0	0
TC-C-142	78	61	181	135	123	0	0	0	0	0
TC-C-146	0	0	62	0	0	0	0	8	0	0
TC-C-148	9	48	119	72	58	3	0	37	1	0
Total	97	893	2014	856	334	9	68	203	3	4
Mean	10.8	99.2	223.8	95.1	37.1	1.0	7.6	22.6	.3	.4

(continued)

Table 12 (continued)

Number of Responses to Different Stimuli on Test Following Wavelength Discrimination
(Wavelength in Mμ - Angular orientation in degrees)

	Mμ = 570				
Subject	30^{o}	60^{o}	90^{o}	120^{o}	150^{o}
TC-C-124	0	0	0	0	0
TC-C-126	0	0	9	0	0
TC-C-130	0	0	0	0	0
TC-C-133	0	0	4	0	0
TC-C-134	13	102	49	30	0
TC-C-136	0	0	1	0	0
TC-C-142	0	0	0	0	0
TC-C-146	0	0	0	0	0
TC-C-148	0	4	48	40	0
Total	13	106	111	70	0
Mean	.1	11.8	12.3	7.8	0

Table 13

Number of Responses to Different Stimuli on Retest Following Wavelength Discrimination

	Mμ = 530					Mμ = 540				
Subject	30°	60°	90°	120°	150°	30°	60°	90°	120°	150°
TC-C-124	0	5	0	0	0	0	53	111	0	0
TC-C-126	0	0	0	0	0	0	0	0	0	0
TC-C-130	3	3	0	8	0	0	30	92	4	0
TC-C-133	0	0	0	0	0	0	2	14	0	0
TC-C-134	0	5	10	10	0	0	2	1	0	0
TC-C-136	0	0	25	0	0	0	3	112	0	0
TC-C-142	0	0	0	0	0	0	0	3	0	0
TC-C-146	0	4	102	3	0	0	0	154	2	0
TC-C-148	23	8	100	81	1	0	10	144	55	2
Total	26	25	237	102	1	0	100	631	61	2
Mean	2.9	2.8	26.3	11.3	.1	0	11.1	70.1	6.8	.2

(continued)

Table 13 (continued)

Number of Responses to Different Stimuli on Retest
Following Wavelength Discrimination

Subject	$M\mu = 550$					$M\mu = 560$				
	30°	60°	90°	120°	150°	30°	60°	90°	120°	150°
TC-C-124	0	2	132	0	0	0	0	1	0	0
TC-C-126	0	0	0	0	0	0	0	0	0	0
TC-C-130	0	41	0	1	0	0	0	0	0	0
TC-C-133	0	0	9	0	0	0	0	0	0	0
TC-C-134	0	19	33	0	0	0	6	0	0	0
TC-C-136	0	0	1	0	0	0	0	0	0	0
TC-C-142	108	93	268	186	124	0	0	0	0	0
TC-C-146	0	0	123	0	0	0	0	10	0	0
TC-C-148	0	1	85	30	0	0	0	0	0	0
Total	108	156	651	217	124	0	6	11	0	0
Mean	12.0	17.3	72.3	24.1	13.8	0	.7	1.2	0	0

(continued)

Table 13 (continued)

Number of Responses to Different Stimuli on Retest Following Wavelength Discrimination

	$M\mu = 570$				
Subject	30°	60°	90°	120°	150°
TC-C-124	0	0	0	0	0
TC-C-126	0	0	0	0	0
TC-C-130	0	0	0	0	0
TC-C-133	0	0	0	0	0
TC-C-134	0	1	9	0	0
TC-C-136	0	0	0	0	0
TC-C-142	0	0	0	0	0
TC-C-146	0	0	0	0	0
TC-C-148	0	3	8	0	0
Total	0	4	17	0	0
Mean	0	.4	1.9	0	0

Table 14

Mean Predicted and Obtained Responses on Generalization Tests Following Wavelength Discrimination

Stimulus	Mean obtained responses	Mean responses predicted by Discrimination Hypothesis	Deviation of predicted from obtained responses	Mean responses predicted by Multiplicative Hypothesis	Deviation of predicted from obtained responses
530 Mμ 30°	56.8	0.0	56.8	44.0	12.8
530 Mμ 60°	174.3	99.7	74.6	159.1	15.2
530 Mμ 120°	164.3	104.7	59.6	162.4	1.9
530 Mμ 150°	21.1	0.0	21.1	12.1	9.0
550 Mμ 30°	22.8	0.0	22.8	47.4	24.6
550 Mμ 60°	116.6	122.9	6.3	172.7	56.1
550 Mμ 120°	119.2	127.9	8.7	176.2	57.0
550 Mμ 150°	50.9	0.0	50.9	13.1	37.8

(continued)

Table 14 (continued)

Mean Predicted and Obtained Responses on Generalization Tests Following Wavelength Discrimination

Stimulus	Mean obtained responses	Mean responses predicted by Discrimination Hypothesis	Deviation of predicted from obtained responses	Mean responses predicted by Multiplicative Hypothesis	Deviation of predicted from obtained responses
560 Mμ 30°	1.0	0.0	1.0	3.8	2.8
560 Mμ 60°	8.2	0.0	8.2	13.9	5.7
560 Mμ 120°	.3	0.0	.3	14.2	13.9
560 Mμ 150°	0.0	0.0	0.0	1.1	1.1
570 Mμ 30°	1.4	0.0	1.4	2.3	.9
570 Mμ 60°	12.2	0.0	12.2	8.3	3.9
570 Mμ 120°	7.8	0.0	7.8	8.5	.7
570 Mμ 150°	0.0	0.0	0.0	0.0	0.0
Standard error (overall)			104.3		25.4
Standard error (530 Mμ, 550 Mμ)			139.3		36.3
Standard error (560 Mμ, 570 Mμ)			6.3		6.0

Table 15

Number of Responses to Different Stimuli on Test
Following Angular Orientation Discrimination

	$M\mu = 530$					$M\mu = 540$				
Subject	30°	60°	90°	120°	150°	30°	60°	90°	120°	150°
TC-T-122	0	0	134	0	0	0	39	82	2	0
TC-T-123	1	0	18	4	1	0	3	33	1	3
TC-T-129	1	13	84	4	1	0	18	146	0	0
TC-T-135	0	100	76	0	0	0	71	58	0	0
TC-T-138	0	0	73	0	0	0	0	132	0	0
TC-T-139	0	0	156	0	0	1	3	305	0	0
TC-T-140	1	8	96	0	0	0	13	82	0	0
TC-T-143	0	1	12	0	0	0	0	1	0	0
TC-T-145	0	24	87	0	0	0	44	168	0	0
Total	3	146	736	8	2	1	191	1007	3	3
Mean	.3	16.2	81.8	.9	.2	.1	21.2	111.9	.3	.3

(continued)

Table 15 (continued)

Number of Responses to Different Stimuli on Test
Following Angular Orientation Discrimination

Subject	$M\mu = 550$					$M\mu = 560$				
	30°	60°	90°	120°	150°	30°	60°	90°	120°	150°
TC-T-122	26	168	157	2	0	0	0	123	4	1
TC-T-123	1	129	189	2	0	20	147	115	21	0
TC-T-129	0	14	148	9	0	0	50	154	0	0
TC-T-135	0	122	127	8	0	0	145	120	0	0
TC-T-138	0	0	152	0	0	0	18	29	0	0
TC-T-139	0	151	298	4	0	0	120	301	0	0
TC-T-140	0	42	140	0	0	0	20	87	3	0
TC-T-143	0	1	92	0	0	0	2	215	0	0
TC-T-145	4	324	451	3	0	0	132	269	0	0
Total	31	951	1754	28	0	20	634	1413	28	1
Mean	3.4	105.7	194.9	3.1	0	2.2	70.4	157.0	3.1	.1

(continued)

Table 15

Number of Responses to Different Stimuli on Test Following Angular Orientation Discrimination

	$M\mu = 570$				
Subject	30^{o}	60^{o}	90^{o}	120^{o}	150^{o}
TC-T-122	0	222	212	0	1
TC-T-123	56	118	235	37	0
TC-T-129	0	29	158	0	0
TC-T-135	0	2	61	0	0
TC-T-138	0	0	160	0	0
TC-T-139	0	133	221	3	0
TC-T-140	0	17	50	0	0
TC-T-143	0	4	188	0	0
TC-T-145	0	193	279	2	0
Total	56	718	1564	42	1
Mean	6.2	79.8	174.0	4.7	.1

Table 16

Number of Responses to Different Stimuli on Retest Following Angular Orientation Discrimination (Wavelength in Mμ - Angular Orientation in Degrees)

	Mμ = 530					Mμ = 540				
Subject	30^{o}	60^{o}	90^{o}	120^{o}	150^{o}	30^{o}	60^{o}	90^{o}	120^{o}	150^{o}
TC-T-122	0	0	48	0	0	0	0	34	0	0
TC-T-123	0	0	2	0	0	0	0	1	0	0
TC-T-129	0	0	7	0	0	0	0	5	0	0
TC-T-135	0	0	7	0	0	0	0	0	0	0
TC-T-138	0	0	1	0	0	0	1	8	0	0
TC-T-139	0	16	2	0	0	0	3	28	0	0
TC-T-140	0	1	3	0	0	0	0	5	0	0
TC-T-143	0	0	0	0	0	0	0	1	0	0
TC-T-145	0	0	0	0	0	0	0	5	0	0
Total	0	17	70	0	0	0	4	87	0	0
Mean	0	1.9	7.8	0	0	0	.4	9.7	0	0

(continued)

Table 16 (continued)

Number of Responses to Different Stimuli on Retest
Following Angular Orientation Discrimination
(Wavelength in Mμ - Angular Orientation in Degrees)

	Mμ = 550					Mμ = 560				
Subject	30°	60°	90°	120°	150°	30°	60°	90°	120°	150°
TC-T-122	0	0	36	0	0	0	0	62	0	0
TC-T-123	0	10	104	0	0	0	19	60	0	0
TC-T-129	0	1	9	0	0	0	0	0	0	0
TC-T-135	0	0	47	0	0	0	47	9	3	0
TC-T-138	0	0	28	0	0	0	0	18	0	0
TC-T-139	0	0	77	2	0	0	0	5	0	0
TC-T-140	0	16	72	2	0	0	1	12	0	0
TC-T-143	0	0	40	0	0	0	0	36	0	0
TC-T-145	0	0	73	0	0	0	0	81	0	0
Total	0	27	486	4	0	0	67	283	3	0
Mean	0	3.0	54.0	.4	0	0	7.4	31.4	.3	0

(continued)

Table 16 (continued)

Number of Responses to Different Stimuli on Retest Following Angular Orientation Discrimination (Wavelength in Mu - Angular Orientation in Degrees)

	$M\mu = 570$				
Subject	30°	60°	90°	120°	150°
TC-T-122	0	34	21	0	0
TC-T-123	0	4	102	0	0
TC-T-129	0	0	1	0	0
TC-T-135	0	7	17	0	0
TC-T-138	0	0	0	0	0
TC-T-139	0	3	2	0	0
TC-T-140	0	0	43	0	0
TC-T-143	0	1	0	0	0
TC-T-145	0	21	92	0	0
Total	0	70	278	0	0
Mean	0	7.8	30.9	0	0

Table 17

Mean Predicted and Obtained Responses on Generalization Tests Following Angular Orientation Discrimination

Stimulus	Mean obtained responses	Mean responses predicted by Discrimination Hypothesis	Deviation of predicted from obtained responses	Mean responses predicted by Multiplicative Hypothesis	Deviation of predicted from obtained responses
530 Mμ 30°	.3	0.0	.3	1.2	.9
530 Mμ 60°	18.1	0.0	18.1	39.1	21.0
530 Mμ 120°	.9	0.0	.9	1.3	.4
530 Mμ 150°	.2	0.0	.2	0.0	.2
540 Mμ 30°	.1	0.0	.1	1.7	1.6
540 Mμ 60°	21.7	0.0	21.7	53.1	31.4
540 Mμ 120°	.3	0.0	.3	1.7	1.4
540 Mμ 150°	.3	0.0	.3	0.0	.3

(continued)

Table 17 (continued)

Mean Predicted and Obtained Responses on Generalization Tests Following Angular Orientation Discrimination

Stimulus	Mean obtained responses	Mean responses predicted by Discrimination Hypothesis	Deviation of predicted from obtained responses	Mean responses predicted by Multiplicative Hypothesis	Deviation of predicted from obtained responses
560 Mμ 30°	2.2	0.0	2.2	2.6	.2
560 Mμ 60°	78.0	48.2	29.8	82.3	4.3
560 Mμ 120°	3.1	0.0	3.1	2.7	.4
560 Mμ 150°	0.0	0.0	0.0	0.0	0.0
570 Mμ 30°	6.2	0.0	6.2	2.8	3.4
570 Mμ 60°	98.7	64.5	34.2	89.4	9.3
570 Mμ 120°	4.7	0.0	4.7	2.9	1.8
570 Mμ 150°	.1	0.0	.1	0.0	.1
Standard error (overall)			14.0		10.2
Standard error (30°, 150°)			2.5		.5
Standard error (60°, 120°)			20.3		14.8

Table 18

Number of Responses to Different Stimuli on Test Following Wavelength and Angular Orientation Discrimination
(Wavelength in Mμ - Angular orientation in degrees)

Subject	Mμ = 530					Mμ = 540				
	30°	60°	90°	120°	150°	30°	60°	90°	120°	150°
TC-TC-120	0	86	102	8	0	11	85	141	120	0
TC-TC-125	0	23	62	4	0	0	12	66	5	0
TC-TC-127	0	23	37	1	0	4	42	126	2	0
TC-TC-131	0	16	126	17	0	0	46	144	0	1
TC-TC-132	0	95	177	0	0	0	195	323	7	0
TC-TC-137	0	40	125	19	0	0	46	64	0	0
TC-TC-141	0	103	153	0	2	4	108	284	69	0
TC-TC-144	0	0	63	0	0	0	0	78	0	0
TC-TC-147	0	4	10	1	0	0	13	216	0	0
Total	0	390	855	50	2	19	547	1442	203	1
Mean	0	43.3	95.0	5.6	.2	2.1	60.8	160.2	22.6	.1

(continued)

Table 18 (continued)

Number of Responses to Different Stimuli on Test Following Wavelength and Angular Orientation Discrimination (Wavelength in Mμ - Angular orientation in degrees)

Subject	Mμ = 550					Mμ = 560				
	30°	60°	90°	120°	150°	30°	60°	90°	120°	150°
TC-TC-120	46	186	169	141	37	0	1	0	1	0
TC-TC-125	7	54	107	8	0	4	22	135	7	0
TC-TC-127	6	137	195	1	0	0	28	18	0	0
TC-TC-131	0	11	168	0	0	0	3	94	0	0
TC-TC-132	0	126	283	0	0	0	95	243	0	2
TC-TC-137	2	41	158	0	1	0	54	47	0	0
TC-TC-141	0	11	361	0	0	0	15	231	9	0
TC-TC-144	0	1	123	0	0	0	0	49	0	0
TC-TC-147	0	2	286	0	0	0	0	0	0	0
Total	61	569	1850	150	38	4	218	817	17	2
Mean	6.8	63.2	205.6	16.7	4.2	.4	24.2	90.8	1.9	.2

(continued)

Table 18 (continued)

Number of Responses to Different Stimuli on Test Following Wavelength and Angular Orientation Discrimination
(Wavelength in Mμ - Angular orientation in degrees)

	Mμ = 570				
Subject	30^{o}	60^{o}	90^{o}	120^{o}	150^{o}
TC-TC-120	0	3	0	0	0
TC-TC-125	0	29	30	3	0
TC-TC-127	0	21	23	1	0
TC-TC-131	0	5	80	0	0
TC-TC-132	0	65	174	0	0
TC-TC-137	0	0	75	10	0
TC-TC-141	0	14	147	3	0
TC-TC-144	0	0	0	0	0
TC-TC-147	0	0	0	0	0
Total	0	137	529	17	0
Mean	0	15.2	58.8	1.9	0

Table 19

Number of Responses to Different Stimuli on Retest Following Wavelength and Angular Orientation Discrimination (Wavelength in Mμ - Angular orientation in degrees)

Subject	Mμ = 530					Mμ = 540				
	30°	60°	90°	120°	150°	30°	60°	90°	120°	150°
TC-TC-120	0	20	38	0	0	0	8	32	0	0
TC-TC-125	0	2	2	0	0	0	17	40	0	0
TC-TC-127	0	0	0	0	0	0	1	10	0	0
TC-TC-131	0	0	35	0	0	0	0	45	1	0
TC-TC-132	0	0	99	0	0	0	9	93	0	0
TC-TC-137	0	0	0	0	0	0	0	1	0	0
TC-TC-141	0	18	161	0	0	0	26	93	0	0
TC-TC-144	0	2	4	0	0	0	0	18	0	0
TC-TC-147	0	0	0	0	0	0	2	12	0	0
Total	0	42	339	0	0	0	63	344	1	0
Mean	0	4.7	37.7	0	0	0	7.0	38.2	.1	0

(continued)

Table 19 (continued)

Number of Responses to Different Stimuli on Retest Following Wavelength and Angular Orientation Discrimination (Wavelength in Mμ - Angular orientation in degrees)

	Mμ = 550					Mμ = 560				
Subject	30°	60°	90°	120°	150°	30°	60°	90°	120°	150°
TC-TC-120	2	45	106	0	1	0	0	1	0	0
TC-TC-125	0	0	27	0	0	0	0	33	0	0
TC-TC-127	0	51	96	0	0	0	10	0	0	0
TC-TC-131	0	0	52	0	0	0	0	58	0	0
TC-TC-132	0	0	36	0	0	0	7	27	0	0
TC-TC-137	0	4	23	0	0	0	0	0	0	0
TC-TC-141	0	46	73	0	0	0	0	120	0	0
TC-TC-144	0	0	65	0	0	0	0	26	0	0
TC-TC-147	0	0	145	0	0	0	0	0	0	0
Total	2	146	623	0	1	0	17	265	0	0
Mean	.2	16.2	69.2	0	.1	0	1.9	29.4	0	0

(continued)

Table 19 (continued)

Number of Responses to Different Stimuli on Retest Following Wavelength and Angular Orientation Discrimination (Wavelength in Mμ - Angular orientation in degrees)

	Mμ = 570				
Subject	30°	60°	90°	120°	150°
TC-TC-120	0	0	0	0	0
TC-TC-125	0	1	16	0	0
TC-TC-127	0	0	0	0	0
TC-TC-131	0	1	16	0	0
TC-TC-132	0	0	0	0	0
TC-TC-137	0	0	0	0	0
TC-TC-141	0	0	89	0	0
TC-TC-144	0	0	25	0	0
TC-TC-147	0	0	0	0	0
Total	0	2	146	0	0
Mean	0	.2	16.2	0	0

Table 20

Mean Predicted and Obtained Responses on Generalization Tests Following Wavelength-Angular Orientation Discrimination

Stimuli	Mean obtained responses	Mean responses predicted by Discrimination Hypothesis	Deviation of predicted from obtained responses	Mean responses predicted by Multiplicative Hypothesis	Deviation of predicted from obtained responses
530 Mμ 30°	0.0	0.0	0.0	3.4	3.4
530 Mμ 60°	48.0	0.0	48.0	38.4	9.6
530 Mμ 120°	5.6	0.0	5.6	8.1	2.5
530 Mμ 150°	.2	0.0	.2	2.1	1.9
540 Mμ 30°	2.1	0.0	2.1	5.1	3.0
540 Mμ 60°	56.7	3.1	53.6	57.4	.7
540 Mμ 120°	22.7	0.0	22.7	12.0	10.7
540 Mμ 150°	.1	0.0	.1	13.1	13.0

(continued)

Table 20 (continued)

Mean Predicted and Obtained Responses on Generalization Tests Following Wavelength-Angular Orientation Discrimination

Stimuli	Mean obtained responses	Mean responses predicted by Discrimination Hypothesis	Deviation of predicted from obtained responses	Mean responses predicted by Multiplicative Hypothesis	Deviation of predicted from obtained responses
560 Mμ, 30°	4.4	0.0	4.4	3.1	1.3
560 Mμ, 60°	26.1	0.0	26.1	34.8	8.7
560 Mμ, 120°	1.9	0.0	1.9	7.3	5.4
560 Mμ, 150°	.2	0.0	.2	1.9	1.7
570 Mμ, 30°	0.0	0.0	0.0	1.9	1.9
570 Mμ, 60°	15.4	0.0	15.4	21.7	6.3
570 Mμ, 120°	1.9	0.0	1.9	4.6	2.7
570 Mμ, 150°	0.0	0.0	0.0	1.2	1.2
Standard error (overall)			24.2		5.2
Standard error (30°, 150°)			1.9		2.5
Standard error (60°, 120°)			35.6		7.2

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